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FOREWORD

When the first exploratory meeting took place which led to the organization of the European Association of Exploration Geophysicists, voices were heard asking for a medium for publications for the members. Naturally some hesitancy seemed indicated when an organization was visualized of some 150 to 200 members. However, in prospecting, surprises, pleasant or otherwise, are always adding interest to life. In this case the very pleasant surprise was that many more scientists in Europe were interested in exploration geophysics than we even dared hope and joined our association, swelling our membership in about one year and a half after the first unofficial meeting to about 450.

Under such favourable conditions it was decided to investigate the possibility of a bulletin. A committee was nominated and various possibilities were considered.

The Association owes a great debt of gratitude to this committee and some others, who in a short space of time managed to present the Council with several proposals. I feel that the names of Dr. Closs and Dr. Schleusener in Germany, Dr. Germain-Jones in England and Dr. Baars in the Netherlands should be mentioned especially for the excellent work they have done on behalf of the Association.

As a result of their efforts the Council was able to place a definite proposal before the meeting in Hanover and this proposal was unanimously adopted. Our bulletin is to be launched as a quarterly and 1953 is to be the year of the first issue.

It is with great pride in this accomplishment of our Association that we started the preparation of the first copy of our bulletin. The outlook seems favourable. A number of very interesting papers are in portfolio and if the co-operation of the members remains as good and enthusiastic as it to-day, the magazine promises to be of a high standard and the future editor will have an easy task. But it will be essential that the conditions mentioned are fulfilled. Without the continued interest and assistance of all of us the task of the editor will become an impossible one instead of an easy one.

There was only a short time available to prepare the first issue in time, if we want our full quotum of four numbers in 1953.

The Council decided not to wait until a permanent editor would be nominated. Dr. Baars was found willing to share with me the editorship temporarily for the first issue(s) until definite arrangements can be made.

The efficient and hearty co-operation of the firm of Brill in Leyden made it possible that our efforts were not in vain and that this foreword can now introduce to the members of the Association and to the outside world the first number of Geophysical Prospecting, official organ of the European Association of Exploration Geophysicists.

A. VAN WEELDEN
President E.A.E.G.
and Editor

THE DESIGN OF ELECTROMAGNETIC GEOPHONES *

BY

A. T. DENNISON **

ABSTRACT

This paper summarizes and extends the published information on the theoretical design of electromagnetic geophones. Both moving-coil and moving-armature instruments are considered, their behaviour compared and various design criteria established.

INTRODUCTION

Although several other types of geophone exist at least in prototype form, the electromagnetic geophone has up to the present maintained its position as the most widely used instrument for seismic prospecting on land. It has therefore been considered desirable, perhaps somewhat late in the day, to collect in one paper some of the main points to be considered in the theoretical design of geophones. Any final design must of course be a compromise between conflicting requirements—and the particular compromise will depend on the particular problem—but the following account details the essential considerations involved.

There are two basic forms of the electromagnetic geophone to be considered, and both these types are currently in use. The first type, and the more widely used one, is the moving coil geophone, the electrical output being produced by the relative movement of a coil and a permanent magnet. The past few years have seen a remarkable reduction in the size of these instruments, the process being stimulated by the requirements of new field techniques. The second type is the reluctance (or moving armature) geophone where the mechanical movement produces a change in the reluctance of a magnetic circuit and hence in the flux through a coil. Although this type of unit is being gradually ousted by the moving-coil type, it has given good service in the past and is by no means a museum piece yet.

These types of geophone will be familiar to all geophysicists and it is unnecessary to describe their particular mechanical forms in detail, though Fig. 1 shows schematically their essential electrical features. Designers may have their own preferences in matters of mechanical design but this paper will be concerned with the basic theoretical considerations.

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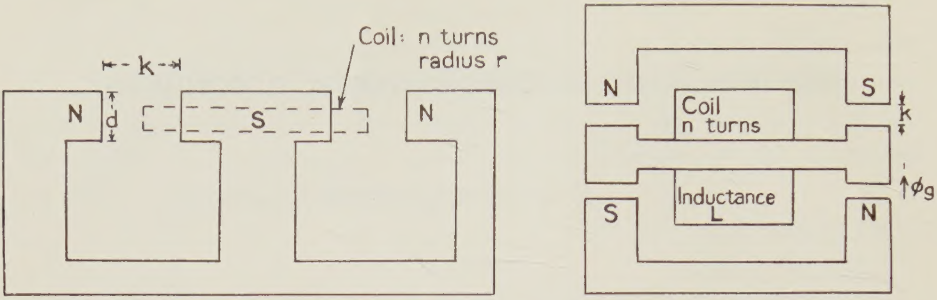
* Presented at the Hague Meeting of the European Association of Exploration Geophysicists, Dec. 15, 1951.

** Anglo-Iranian Oil Company Limited.



(a) Moving-coil Geophone (b) Reluctance Geophone

Fig. 1. Schematic Diagrams of Electromagnetic Geophones.

I—The General Geophone Equation

It will be convenient to use the following symbols:

M: the seismic (suspended) mass.
S: the effective stiffness of the suspension.
r: the mechanical damping factor.
x: the displacement of the ground.
L: the inductance of the geophone coil.
R: the total resistance of the coil and its external circuit.

The basic geophone equation relates the current i, produced by the geophone in its load resistance, with the ground displacement, x, producing this current. It may be shown (1, 2) that for either type of geophone this relation is given by

$$\frac{d^3i}{dt^3} + \left(\frac{R}{L}+\frac{r}{M}\right)\frac{d^2i}{dt^2} + \left(\frac{S}{M}+\frac{rR}{ML}+\frac{K^2}{ML}\right)\frac{di}{dt} + \frac{SR}{ML}i = \frac{K}{L}\frac{d^3x}{dt^3} \quad . \quad . \quad . \quad (1)$$

In the references quoted, the equation is not given in this form but may be derived from the expressions given there. K is a constant depending on the design of the geophone.

For the moving coil type, S is the mechanical stiffness of the suspension and K is given by

$$K = H.2\pi nr.$$

where n is the number of turns on the coil. H is here the magnetic field in the gap and r is the mean radius of the coil.

For the reluctance geophone, S, the effective stiffness, is given by $S = S' - S''$ where S' is the mechanical stiffness of the suspension and $S'' = \frac{\varphi^2}{\pi Ak}$ is the negative stiffness arising from magnetic forces.

K in this case is given by

$$K = \frac{2n\varphi}{k}$$

φ is here the flux in each of the four air gaps,
n is the number of turns on the coil,
A is the area of the magnetic poles,

and k is the distance between the armature and each pole face in the equilibrium position.

Since the behaviour of both types of geophone can be represented by the above differential equation, it is clear that there must be a very close similarity in their behaviour. This similarity will however be slightly modified by the fact that in one case K and S are independent and in the other case are, in part, interdependent: the effect of this difference on the design of the two types will be seen in the discussion on damping conditions. In their general behaviour however, the moving coil and reluctance types are identical.

The reluctance geophone may also be built in a form somewhat different from Fig. 1(b), with the centre limb forming the permanent magnet. The coil is then split, the two halves being mounted on the upper and lower limbs respectively; these limbs now form the armatures. Whilst this modification has certain advantages, the total number of turns must be doubled in order to obtain the same output current. The equation is then identical with that above, n now being the number of turns on either coil and L the total inductance.

II—Equivalent Circuits for Geophones

(a) *General*

An electromechanical device such as a geophone is somewhat difficult to handle in the laboratory since the mechanical movements to be produced are usually complex in character and small compared with the ground movements encountered in a laboratory. Whilst these problems can be overcome, by the use of some form of shaketable, it is often more convenient to use an "equivalent circuit" for the geophone (3) : this is particularly so when it is desired to investigate the response to transient phenomena. For many designers, the equivalent circuit has the added advantage that, being made up of electrical components only, its behaviour is more readily appreciated than that of a mixed electrical-mechanical system.

The equivalent circuit for a geophone may be defined as a purely electrical circuit which, when supplied with an electrical input bearing a definite relation to the ground displacement, produces an output current identical with that produced by the geophone itself for the same ground displacement. For example we may have an equivalent circuit where the input is in the form of a voltage proportional to the ground velocity or one where the input is a current proportional to the ground acceleration.

The equivalent circuit may take many forms but the two to be described are usually considered to be the most useful.

(b) *Theory*

The equivalent circuit will duplicate the output of the geophone if the differential equation of its output current is identical with that of the geophone as given in (1) above.

Consider now the circuit shown in Fig. 2(a). It may be shown by simple electrical theory that the current i produced in the resistor R′ when a current I is supplied to the input terminals, is given by the equation

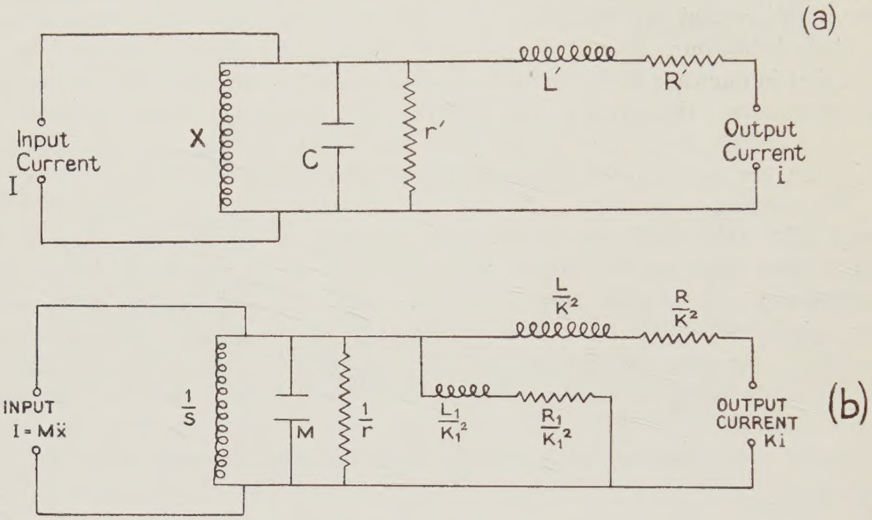


Fig. 2. Equivalent Circuits.

$$\frac{d^3i}{dt^3}+\left(\frac{R'}{L'}+\frac{1}{Cr'}\right)\frac{d^2i}{dt^2}+\left(\frac{1}{CX}+\frac{1}{CL'}+\frac{R'}{CL'r'}\right)\frac{di}{dt}+\frac{R'}{CL'X}i=\frac{1}{CL'}\frac{dI}{dt}\quad . \quad . \quad (2)$$

if we compare this with equation (1)

$$\frac{d^3i}{dt^3}+\left(\frac{R}{L}+\frac{r}{M}\right)\frac{d^2i}{dt^2}+\left(\frac{S}{M}+\frac{K^2}{ML}+\frac{rR}{ML}\right)\frac{di}{dt}+\frac{SR}{ML}i=\frac{K}{M}\frac{d^3x}{dt^3}$$

we see that the equations are of the same form and by suitable choice of the circuit constants, we may make equation (2) identical with equation (1).

It is convenient in practice to make R′ = R, the geophone load resistance. The equations will then be identical if values are chosen such that

$$L' = L \quad , r' = K^2/r$$

$$C = M/K^2,$$

$$X = K^2/S \text{ , and } \frac{dI}{dt} = \frac{M}{K}\frac{d^3x}{dt^3} \text{ or } I = \frac{M}{K}\frac{d^2x}{dt^2}$$

If then we construct the electrical circuit of Fig. 2(a) giving the components these values, we may obtain the geophone output for a ground displacement x by injecting the current I given by the above expression.

It is thus possible to build up in the laboratory a device including only standard and stable electrical components, with which we can reproduce the geophone response for any desired ground movement. This ground movement must be transformed into an electrical signal in accordance with the equation given above this is not usually difficult.

The equivalent circuit given above is a useful one for calculations and when a step function of $\frac{d^2x}{dt^2}$ is required. For other types of input it may be more convenient to use the equivalent circuit of Fig. 2(b) where the input is in the form of a voltage rather than a current. It may be shown that the differential equation of this circuit is

$$\frac{d^3i}{dt^3} + \left(\frac{R'}{L'} + \frac{1}{Cr'}\right)\frac{d^2i}{dt^2} + \left(\frac{1}{CX} + \frac{1}{CL'} + \frac{R'}{CL'r'}\right)\frac{di}{dt} + \frac{R'}{CL'X}\,i = \frac{1}{L}\frac{d^2V}{dt^2} \quad . \; . \; . \quad (3)$$

The left hand side of this equation is identical with that of (2) above and the equation will therefore be identical with equation (1) if the components have the values given for (2) and if

$$\frac{d^2V}{dt^2} = K\frac{d^3x}{dt^3} \quad \text{or} \quad V = K\frac{dx}{dt}$$

For most types of ground motion, the circuit of Fig. 2(b) is more convenient to use since we only require a voltage proportional to the first differential whereas the first method requires a signal proportional to the second differential of the ground displacement.

(c) *Experimental Aspects*

The required ground motion must first be translated into the equivalent electrical signal which will usually be a voltage. This presents no difficulty in cases where the motion is a pure sine wave or where it is a step function. Certain simple transient forms may also be derived by differentiation or integration of a step function. If the more complex wave trains, found in field work, are required it may be necessary to use more complex methods such as a photoelectric cell responding to a previously drawn curve of ground movement.

The voltage produced by these methods will require differentiation and this may be achieved with sufficient accuracy by a simple R-C network though with a considerable reduction in the available voltage. This reduction can usually be tolerated in the case of voltage feed (Fig. 2b) since only a single differentiator is involded. The differentiator must in any case have a low impedance output in order that V shall be independent of the equivalent circuit. With the current feed system of Fig. 2(a) the loss in voltage in the two differentiators is a serious disadvantage, particularly since this voltage source must then be converted to a current source, say by a large series resistor.

The values of the circuit components may be obtained from electrical measurements on the particular geophone, these measurements being carried out at voltage levels similar to those found in practice. Thus by measuring the impedance with the suspension clamped we may find L′ and the internal component of R′. With the suspension unclamped, we have two frequencies at which the impedance is purely resistive. As the lower of these (f_0) we have

$$f_0^2 \simeq \frac{1}{4\pi^2 X C}$$

and at the higher (f_1) we have $X = L'.\left(\frac{f_1^2}{f_0^2} - 1\right)$

These expressions are slightly modified if r′ is not large but the correction is quite small in many cases.

L′ and the internal component of R′ will be found to vary with frequency and it is convenient to replace these components of the analogue by a clamped geophone, the suspension being very firmly clamped to prevent mechanical vibration. The inductance X should theoretically have zero resistance: whilst this is impossible it may be possible to keep its resistance negligible if r′ is not too great. In any case, it is usually possible for the resistance to be negligible when the equivalent circuit is operating into a practical load.

(d) *Uses and Limitations*

In testing equipment, there is often a need for a system which will reproduce a particular ground motion exactly since field tests will usually give rather different ground motions when repeated. Such a system may be an equivalent circuit of the above type or a "shake-table" of some kind. The earlier forms of shake-table are only suitable for steady state measurements, i.e. sinusoidal ground motion, but the development of a crystal shake-table (4) and of feed-back systems (5) should enable transient phenomena to be studied. The crystal shake-tables are somewhat expensive however, and this would be more especially so for one to carry heavy geophones. The equivalent circuit on the other hand gives us a simple device for the study of both steady state and transient phenomena which is also independent of any external mechanical vibrations.

Nevertheless it has two important limitations, the first being that it must be rebuilt for each type of geophone to be studied. This is not difficult except for the inductance X which may have values between 1 and 200 Henries: such values are not usually obtainable in variable form and given inductances will vary somewhat with the applied voltage. Nevertheless, the accuracy of X can often be of the same order as variations from one geophone to another of the same type.

The other major limitation is that inherent in the theory of the device. The circuit behaviour has been shown to be equivalent to that of the geophone as expressed in equation (1) but this equation is basically an approximate one —though the most accurate which is of practical use. The non-linearity of L and R with frequency may be allowed for in the practical circuit, but K itself is not strictly a constant. * In the derivation of equation (1) it is assumed that the EMF set up in the geophone coil is a linear function of the velocity of the seismic mass: with this assumption, the equation holds whatever the particular form of K. If the relationship is non-linear, K will vary slightly with the displacement and this may occur in either type of geophone. There are also terms involving mechanical and magnetic hysteresis which have been neglected and these may be considered as modifying the X—r′ combination. Silverman (6) shows that a closer approximation to equivalence may be obtained by adding a resistance to the X branch of the circuit. This addition simplifies the design of a suitable inductance but the choice of the additional resistance must be largely empirical.

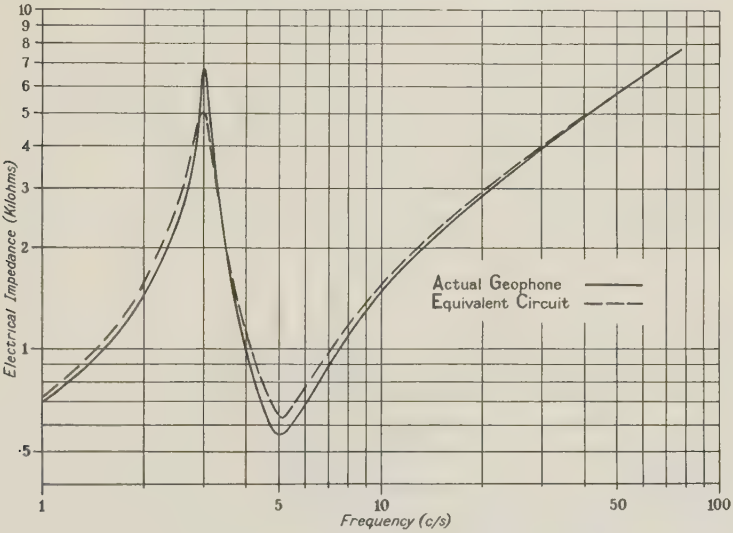


Fig. 3.

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* See Chakrabarty (10) for a discussion of the reluctance geophone.

Even without this correction, a fairly close agreement can be reached as shown in Fig. 3 which compares the geophone impedance and the circuit impedance for an electrical input to the geophone terminals. There is a major discrepancy at the natural frequency owing to the low Q value for the inductance X but elsewhere the agreement is close. For a mechanical input, the discrepancy at 3 c/s would largely disappear for loads of 3000 ohms or less across the geophone terminals. The values for this circuit are:

$X = 46$ Henries

$C = 55\ \mu F$

$\left.\begin{matrix} L \\ R \end{matrix}\right\}$ varying with frequency but approximately 25 Henries and 500 ohms at 1 c/s.

III—GEOPHONE DAMPING

(a) *The Ideal Geophone*

If in the geophone of equation (1), we can neglect L, the expression becomes,

$$\frac{d^2i}{dt^2} + \left(\frac{r}{M} + \frac{K^2}{RM}\right)\frac{di}{dt} + \frac{S}{M}i = \frac{K}{R}\frac{d^3x}{dt^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This is the equation of a geophone whose self-inductance is small and putting

$$\left(\frac{r}{M} + \frac{K^2}{RM}\right) = 2hw_o \qquad \text{where } w_o^2 = \frac{S}{M}$$

we have $\dfrac{d^2i}{dt^2} + 2hw_o\dfrac{di}{dt} + w_o^2 i = \dfrac{K}{R}\dfrac{d^3x}{dt^3}$, a well known type of expression.

h is here the ratio of the damping term to that required for critical damping and will clearly depend both on r, the mechanical losses, and the load resistance R, a small value of R giving a high value of damping. R here includes both the load resistance and the internal resistance of the geophone. If f_o is the natural frequency, we have $w_o = 2\pi f_o = (S/M)^{1/2}$

As h is varied, both the steady state (4, 6) and the transient response change typically and the nature of these responses may indeed be used to determine h. Fig. 4 shows the amplitude and phase response to steady state ground motion and the transient response to a step function of ground acceleration. The latter is equivalent to the response obtained when the seismic mass of a geophone is depressed and suddenly released, a well known test for geophones. The overshoot, i.e. the ratio of the amplitude of the second peak to that of the first (neglecting sign differences) is usually measured.

It may be shown that this overshoot α is given by:

$$\alpha = e^{\frac{-h\pi}{\sqrt{1-h^2}}}$$

which enables h to be calculated if α is known.

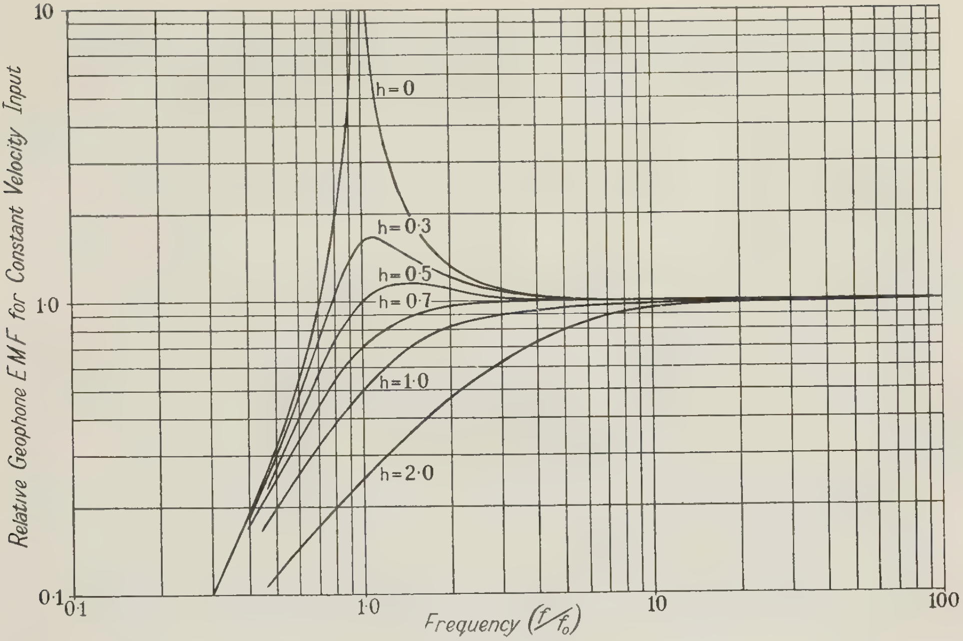

10
1·0
0·1
0·1
1·0
10
100
Relative Geophone EMF for Constant Velocity Input
Frequency (f/f_0)
h=0
h=0·3
h=0·5
h=0·7
h=1·0
h=2·0

Fig. 4 (a).

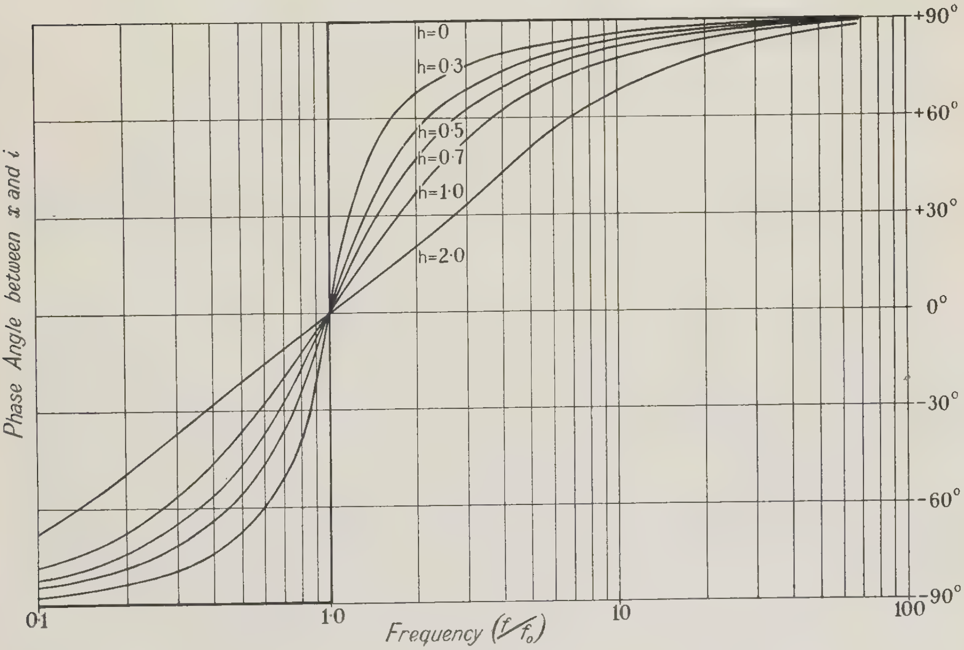

+90°
+60°
+30°
0°
−30°
−60°
−90°
0·1
1·0
10
100
Phase Angle between x and i
Frequency (f/f_0)
h=0
h=0·3
h=0·5
h=0·7
h=1·0
h=2·0

Fig. 4 (b).

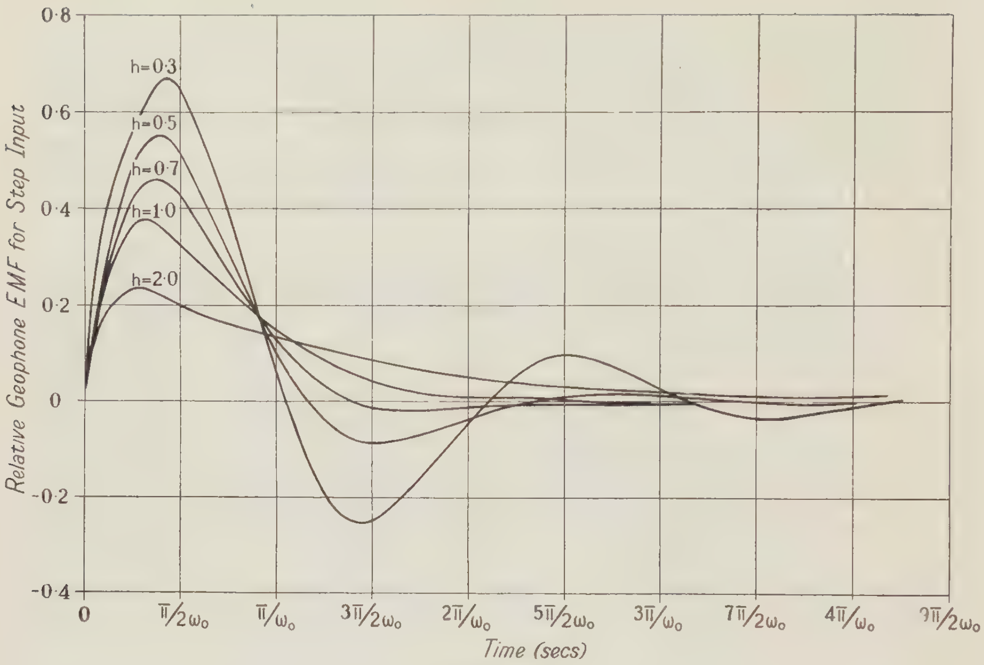


Fig. 4 (c).

When the mechanical damping is negligible ($r = 0$), we have from the definition of h:

$$h = \frac{K^2}{2\,RMw_0}$$

Thus any particular value of h may be realised by suitable choice of R.

(b) *Practical Geophones with Finite Inductance*

Most of the geophones found in practice have an appreciable value of L, the self inductance, and in this case the above conclusions no longer hold. Firstly, we shall see that there is a limit, when r is zero, to the degree of damping which can be realized by variation of R. Secondly, the responses shown in Fig. 4 are considerably modified by the impedance of the inductance. At higher frequencies, this impedance will be large in comparison with R and there will be an increasing reduction of the output voltage. This is clearly seen in Fig. 5 showing an extreme but practical case for a heavy geophone.

If we put $r = 0$ in equation (1) we have,

$$\frac{d^3i}{dt^3} + \frac{R}{L}\frac{d^2i}{dt^2} + \left(\frac{S}{M} + \frac{K^2}{ML}\right)\frac{di}{dt} + \frac{SR}{ML}i = \frac{K}{L}\frac{d^3x}{dt^3} \quad . \quad . \quad . \quad . \quad (5)$$

There is no expression corresponding to that of h above but we may still define critical damping as that which gives no oscillatory term when a step function of ground acceleration is applied.

Sparks and Hawley (7) have previously stated that this occurs (for the limiting case) when both

$$\frac{w_1}{w_0} \geqslant 3.26 \quad \ldots \quad 6(a)$$

$$\text{and} \quad \frac{R}{L} = \frac{w_1^2 + w_0^2}{2\, w_0} \quad \ldots \quad 6(b)$$

$$\text{where} \quad w_0^2 = \frac{S}{M} \quad \text{and} \quad w_1^2 = \frac{K^2}{ML} + \frac{S}{M}$$

Inspection of their analysis shows it to be incomplete however: the condition quoted is mathematically sufficient but not necessary. If the oscillatory term of the step-function response is $e^{-\alpha t} \sin (wt + \varphi)$, equation 6(b) gives the value of R/L at which α is a maximum. Equation 6(a) is then the limiting condition for w to be zero for this value of R. It is implicit in the paper quoted that the value of R giving maximum α also gives the minimum value of w. This is not correct however and it may be shown that the limiting condition for w to be zero is

$$\frac{w_1}{w_0} \geqslant 3 \quad \ldots \quad 6(c)$$

$$\text{and} \quad \frac{R}{L} = \left[\frac{w_1^4 + 18\, w_1^2\, w_0^2 - 27\, w_0^4}{8\, w_0^2}\right]^{1/2} \quad \ldots \quad 6(d)$$

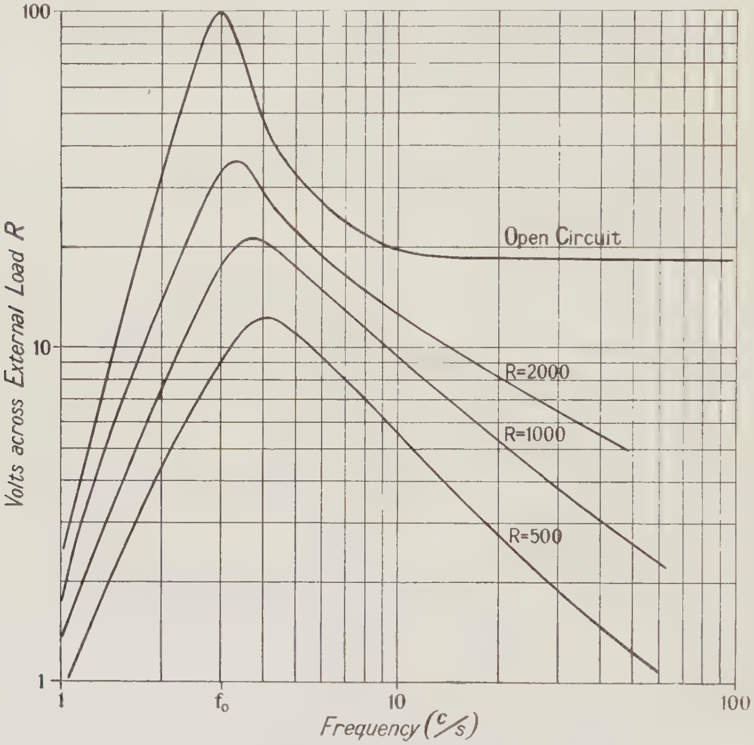
For damping less than critical ($w > 0$) equation 6(b) gives the value of R for maximum α but equation 6(d) gives only an approximate value of R for minimum w. This illustrates the difficulty of defining damping, other than critical damping, in such cases.

If, in a given geophone, $\frac{w_1}{w_0} = 3$, then it will be critically damped at a value of R given by equation 6(d). If R is increased from this value, the geophone response varies in a similar way to that of the ideal instrument of Fig. 4 as h is reduced from unity, except for the high frequency attenuation mentioned earlier. If however R is reduced, the damping does not increase: instead, an oscillatory term appears again in the transient output, its relative amplitude increasing as R becomes smaller.

If $\frac{w_1}{w_0} < 3$, the maximum value of damping will be less than critical, i.e. no matter what value of R is taken, critical damping cannot be achieved.

If $\frac{w_1}{w_0} > 3$, there will be a range of values of R, on either side of that given by equation 6(d), for which the geophone is more than critically damped. For values of R above and below this range, the transient response contains an oscillatory term.

The reason for this behaviour is perhaps most clearly seen in the equivalent circuit of Fig. 2(a). In this case r′ is taken as infinite. Now if R is very large, we have effectively an undamped circuit formed by C and X. If on the other hand R is small, we have a second undamped circuit formed by C with L′ and X in parallel. There will clearly be an intermediate value for R which will give the maximum damping.



Response to Constant Velocity Input

Fig. 5 (a).

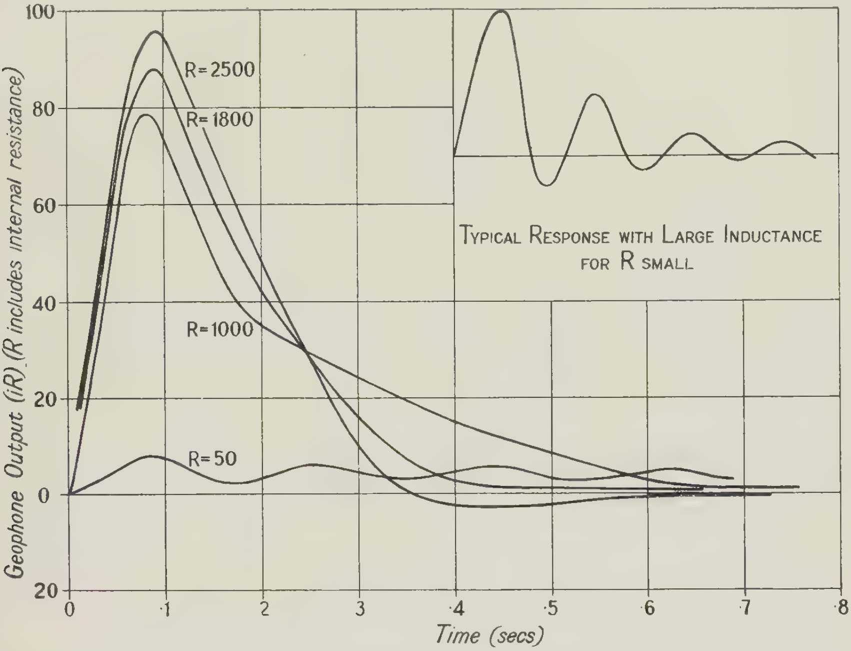
With R infinite, the frequency of oscillation following a transient will be given by $w^2 = (2\pi f)^2 = \frac{1}{LC}$ or $\frac{S}{M}$ substituting the values from II above. This w is thus identical with the w_0 quoted above.

Similarly if R = 0,

$$w^2 = (2\pi f)^2 = \frac{1}{C}\left(\frac{1}{L}+\frac{1}{X}\right) \text{ or } \frac{S}{M}+\frac{K^2}{ML}$$

which is the value for w_1^2 quoted above.

As R is increased from 0, the frequency of oscillation will fall to a minimum (at zero if critical damping is reached) and then rise again to f_0 when R is infinite. This is illustrated in the following set of equations giving the response of a geophone to the step function for different values of R. This geophone is similar to the one whose steady state response is shown in Fig. 5(a) and has a very small amount of internal damping.



Response to Step Function Input
Fig. 5 (b).

R = 10,000 $24.3\,i = 32.5\,e^{-4t}\sin(12.1\,t - .031) + e^{-397\,t}$

R = 1,900 $0.44\,i = 14.4\,e^{-15\,t}\sin(2.5\,t - .07) + e^{-58\,t}$

R = 1,800 $0.39\,i = 4\,e^{-43\,t} + 6\,e^{-11\,t} - 10\,e^{-24\,t}$ (critical damping).

R = 1,750 $0.16\,i = 8.2\,e^{-32.6\,t}\sin(2.8\,t + .12) - e^{-9.8\,t}$

R = 50 $0.22\,i = e^{-3.4\,t}\sin(36.8\,t + 1.48) - e^{-0.23\,t}$

Some of these transient responses are shown in Fig. 5(b). In general, the transient response has the form of a damped oscillation whose axis is not a straight line but an exponential curve. This is most clearly seen in the inset to Fig. 5(b) which is the response of a geophone which cannot be critically damped.

We thus have the position that for geophones of finite inductance, we cannot produce critical damping by the load resistor unless $w_1/w_0 > 3$. When critical damping can be produced, the load resistance required will be greater by an amount Lw_0 than that required if the inductance were absent.

We may also note here that if f_0 and f_1 are the two frequencies where the geophone electrical impedance is purely resistive,

$$2\pi f_0 \equiv w_0$$

$$\text{and } 2\pi f_1 \equiv w_1$$

The ratio w_1/w_0 may thus be quickly found by electrical measurements.

(c) *Design Limitations*

Assuming that critical damping is required in the geophone, we may investigate the design limitations imposed by the above criterion. If a damping factor less than critical is required, the design limitation will be less stringent than that given by this expression.

Reluctance Geophone

We have from above $\frac{w_1}{w_0} > 3$ or substituting

$$\frac{K^2}{SL} + 1 > 9$$

If we now substitute the values of S and K given in I we have

$$\frac{4n^2\varphi^2}{k^2 L} \times \frac{1}{\left(S' - \frac{\varphi^2}{\pi A k}\right)} > 8$$

Assuming that the leakage inductance is negligible we may write $L = \frac{4\pi n^2 A}{k}$ and substituting and simplifying we have

$$\frac{S''}{S'} > 0.89 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Thus the negative stiffness due to the magnet must be at least 90 % of the mechanical stiffness of the suspension, i.e. the effective stiffness must be less than 10 % of that of the suspension stiffness alone. Such a condition can be realized in a laboratory instrument but is not practicable in the field owing to a non-linearity of the S'' term.

A more accurate formula for S'' is $\frac{\varphi^2}{\pi A k}\left(1 + \frac{2x^2}{k^2}\right)$

where x is the displacement of the seismic mass. For the small values of x occurring during recording, the x^2 term is here negligible. Appreciable values of x will however occur in the field during setting-up and transit and if x becomes greater than $\frac{k}{4}$ we see that S″ (= 0.9 S′ for small amplitudes) becomes greater than S′. The effective stiffness is then negative and the suspension will "stick" in the displaced position. Whilst x could be held smaller than this value by suitable adjustment of stops, the drift of the instrument's equilibrium position, arising from temperature changes, would necessitate continuous readjustment.

It is therefore impracticable to use an externally damped reluctance geophone if critical damping is required. If the damping criterion is less severe however it may well be possible to use such a geophone, more especially since there is inevitably some slight internal damping due to eddy currents. It is fairly easy to obtain a stable system with S″ = 0.7S′ and this would correspond very approximately to a damping factor of 0.5 at the value of R for maximum damping. This figure is probably as high as can conveniently be reached in a field instrument.

If a higher degree of damping is required, other methods of damping must be used.

There will usually be a leakage inductance, L″, arising from the magnetic flux due to the coil currents not lying entirely within the magnet gaps. This component has been neglected above but if it is appreciable, the condition given by (7) becomes,

$$\frac{S''}{S'} > 0.89 \left(\frac{1}{1 - \frac{.11\,L''}{L}} \right)$$

for critical damping to be possible. Any increase of L″ in relation to the total inductance L will thus increase the value of S″ required and is to be avoided.

Moving Coil Geophone

As before the limiting condition is:

$$\frac{K^2}{SL} + 1 > 9$$

or substituting from (1)

$$\frac{(2\pi nrH)^2}{SL} > 8$$

S is here independent of K and L, depending only on the mechanical design. There will however be a relation between K and L since both are partially dependent on the geometry of the design.

In general L will be given by a formula of the type $L = 4\pi n^2 rB$ where B will be a complex term depending on the shapes of the coil and of the metal near it.

If we simplify the problem by assuming that all the turns of the coil lie in the same plane and that all the flux due to the current in the coil is retained in the magnet gap, we may write

$$L = \frac{2\pi^2 n^2 rd}{k}$$

where k is the separation of the polefaces and
d the depth of the polefaces.

Substituting this value above we have $\frac{2rH^2k}{Sd} > 8$ or since $H^2 = \frac{P}{V}$ where P is the effective power of the magnet and V the volume of the air gap

$$\frac{P}{Sd^2} > 25 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

The expression used here for L is of course very approximate but measurements indicate that it provides a reasonable approximation for design purposes.

In this case, for a given spring stiffness S we can always meet the condition by increasing P or reducing d. There is however a physical limit to d since it will usually be of the same order as the length of the coil and space requirements may be against an increase of k to maintain the coil volume. P however can be considerably increased using the latest magnetic materials and there should be little difficulty in meeting the requirements. It may be noted however that many older moving coil geophones do not meet this condition since they were designed to be used with less than critical damping. The Willmore geophone (8) on the other hand is an example of one which can be critically damped by purely external loading.

(d) *Other types of damping*

It is usually desirable to make the load resistance provide all the required damping since this resistance then has its minimum value and the power output is a maximum. Owing to the above restrictions however, this may not be practicable and it may be necessary to have recourse to oil damping. The geophone is usually filled with a suitable oil whose viscosity increases r (equation (1)) and so provides the required internal damping. This method has the disadvantages of increasing the geophone weight and of introducing temperature-variable damping. In consequence, it is now being used mainly in special applications.

Many moving-coil geophones include a certain amount of internal electromagnetic damping, approximately corresponding to a value of 0.3 for h, and this method is sufficiently widespread to warrant further discussion here. The usual system is to wind the geophone coil on a metallic former, this being very convenient mechanically. The former then acts a second coil terminated by its own resistance and so produces damping. There is also a close coupling between the former and the geophone coil which must be considered.

These effects are shown in terms of the equivalent circuit in Fig. 6. Fig. 6(a) is here a more convenient variation of the circuit given earlier in Fig. 2(a). If i is the geophone output current, the output of this circuit is Ki. Fig. 6(b) shows the effect of adding the second coil and in Fig. 6(c) we also have the mutual coupling of the two coils.

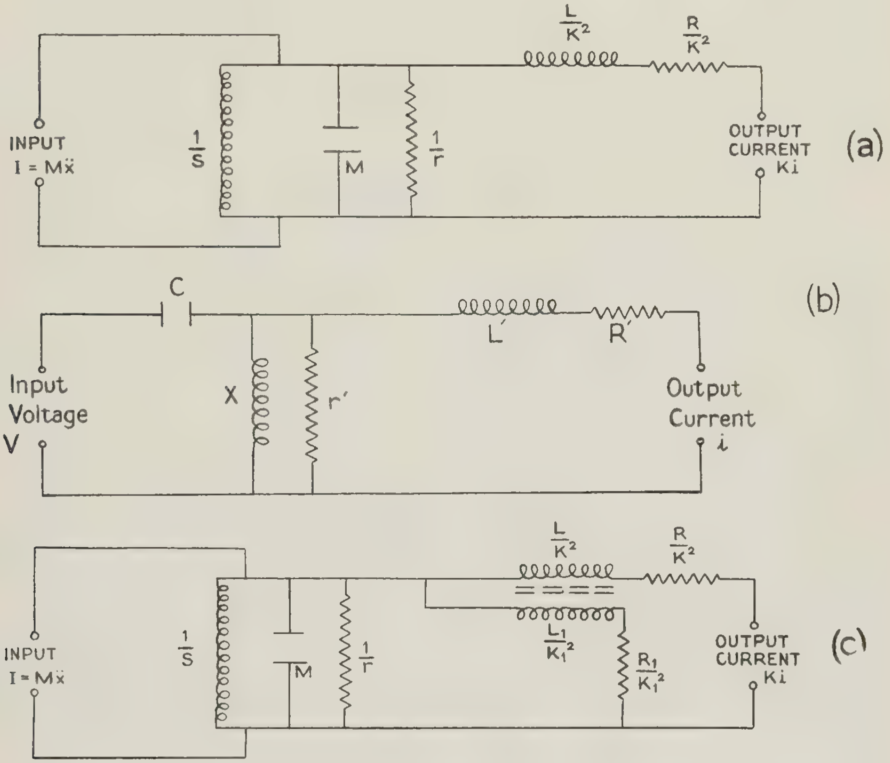


Fig. 6.

Assuming that the ratio $L : L_1$ is given by $n^2 : 1$, we may calculate the differential equation of the modified geophone for close coupling of the coils. This may be shown to be, neglecting r,

$$\frac{d^3i}{dt^3} + \frac{R}{aL}\frac{d^2i}{dt^2} + \left(\frac{S}{M} + \frac{K^2}{ML}\right)\frac{di}{dt} + \frac{SR}{MaL}\,i = \frac{K}{aL}\,\dddot{x} \quad . \quad . \quad . \quad (9)$$

which is to be compared with equation (5).

a is here given by $a = 1 + \dfrac{R}{n^2R_1}$ and will usually lie between 1 and 2.

Equations (4) and (5) are identical if R in (5) is replaced by R/a and the $\ddot{x}$ term is multiplied by 1/a.

The criterion for maximum damping (6a) thus becomes $\frac{R}{aL} = \frac{w_1^2 + w_0^2}{2 w_0}$ i.e. the required value of R is higher than if the coil former were absent. The criterion $\frac{w_1}{w_0} > 3$ is however unchanged.

It may be shown from (9) that, when r may be neglected,

(a) the resistance required for maximum damping is increased by the factor a,

(b) the characteristics w_0 and w_1 are unchanged and w_1/w_0 must still be greater than 3 for critical damping to be possible, and

(c) the voltage output of the geophone (across R) is unchanged if R is increased by the factor a, though the power output is of course reduced. As a corollary of this, the geophone frequency response in unchanged.

Thus if the initial assumptions hold, coil-former damping does not reduce the criterion for critical damping and does not modify the frequency response. The required load resistance is however increased and remembering that the geophone will have an appreciable internal resistance, it follows that the available output voltage is also increased. For example, if the internal and external components of R were equal with no internal damping, a value of 1.5 for a would raise the effective output voltage by 30 %. As pointed out later, there is a limit to the permissible increase of load resistance.

If coil-former damping is present, the electrical impedance looking into the geophone terminals will be reduced and the equivalent circuit calculations become more complicated. The measured values of w_0 and w_1 (zero reactance) will be unchanged however.

Whilst coil-former damping is usually confined to moving coil instruments, the above analysis applies equally to the reluctance type of instrument. These geophones can therefore be similarly damped by using a metal former or its equivalent.

IV—Choice of the Degree of Damping

If the damping of a geophone is appreciably less than critical, two important effects arise. Firstly, the velocity sensitivity of the instrument is greatest at a frequency given by

$$f = f_0 (1-2h^2)^{-\frac{1}{2}}$$

where f_0 is the natural frequency of the suspension. There will thus be a relative amplification of signals having a strong component at this frequency which may obscure wanted signals of other frequencies. Further, if this frequency should coincide with that of an unwanted background, the resulting seismogram may be of little value.

The second effect produced by an underdamped geophone is essentially a transient effect. It has been shown above that for a step input of acceleration, the geophone output includes a damped oscillatory term when h is less than 1; a similar result is obtained for all types of ground transient. This oscillatory term is introduced by the geophone and will add an artificial component to the record which may be misleading if the frequency of oscillation is close to the ground frequencies of interest. The question of 'resolution' also arises here. The arrival of a ground transient is easier to 'pick' if the arrival occurs after a steady trace on the record. Two consecutive arrivals are therefore more easily distinguished if the response of the geophone to the first has died away quickly and this will involve a high degree of damping.

For reflection prospecting, a high degree of resolution is required and, ideally, critical damping of the geophone is desirable. As can be seen from Fig. 4 however, such damping involves an appreciable loss of sensitivity at the lower frequencies and in many cases this loss cannot be tolerated. This applies particularly to the use of 30 c/s geophones. Damping values of 0.5 have therefore been used in practice, but a better compromise will usually be a value of 0.7 for h. This has very little loss of low frequency sensitivity (3db. down at the natural frequency) and has a very small oscillatory component in its response to transients (Fig. 4). This oscillatory component will have a frequency equal to 0.7 times the geophone's natural frequency and will therefore be subject to further attenuation in many seismic equipments. If full critical damping is used it will be necessary to use a geophone of lower natural frequency.

In refraction recording, the conditions are somewhat different. If only the first arrival is required, considerations of resolution are unimportant and it is usually necessary to maintain the low frequency response as far as possible. A peaky response should still be avoided if accentuation of ground frequencies near the natural frequency is to be avoided and a value of 0.5 for h is usually suitable. The resonance peak here is small and the low frequency response is well maintained. For "later-arrival" refraction work, resolution is again needed and a value between 0.5 and 0.7 will be suitable: in many cases, the improved low frequency response for 0.5 will make this value of h preferable.

It has been assumed in the above discussion that an ideal geophone is being used: the presence of inductance will of course modify the response as previously described but similar considerations will still be valid.

V—The Geophone Voltage Sensitivity

For the ideal geophone of equation (4) we can derive the following relations when r may be neglected

$$R = \frac{K^2}{2hMw_0}$$

and

$$V = \frac{Kv\,w^2}{\{(w^2 + w_0^2)^2 - 4\,w_0^2 w^2 (1 - h^2)\}^{1/2}}$$

where V is the steady-state voltage across R for a ground pulsatance w and (peak) ground velocity v. For frequencies much higher than the natural frequency, this becomes

$$V = Kv$$

This corresponds to the flat part of the curves of Fig. 4(a).

The power output (W) is given by

$$W = \frac{v^2\,M\,w_0\,.\,h\,.\,w^4}{(w^2 + w_0{}^2)^2 - 4w_0{}^2w^2(1-h^2)} \text{ or } v^2Mhw_0 \text{ when } w \gg w_0.$$

This equation is of importance when the geophone feeds a galvanometer directly (8) but most seismic equipment uses valve amplifiers which are primarily voltage sensitive devices.

From the above expression, K may be regarded as the (voltage) velocity sensitivity of the geophone and knowing K and h, the response curve of the instrument may be calculated. K is usually of the order of 1 volt/cm./sec. This output voltage is however the voltage across R and the geophone resistance (R_i) forms part of R. The available external voltage is therefore given by

$$V_0 = \frac{Kv.\ (R - R_i)}{R}$$

and it is clearly important to keep R_i as small as possible.

If the geophone also has inductance L, this output then becomes

$$V_e = \frac{Kv.\ (R - R_i)}{(R^2 + L^2w^2)^{\frac{1}{2}}}$$

again for frequencies much higher than the natural frequency.

These expressions are still valid when the geophone has some internal damping but the load resistance R will then be higher.

For geophones with appreciable inductance, the equivalent circuit of Fig. 2(a) will be found useful for calculations of the response curve, these calculations requiring only simple electrical theory. The circuit constants can be found as described earlier and K, S or M must also be measured. M or S can usually be found fairly simply; if required, K can be found from

$$mg = Ki$$

where m is a mass added to M and i is the D.C. current required to return M on its previous equilibrium position.

It may be noted that from these relationships, the voltage output of the geophone is independent of M. In many cases, however, M is important as the following sections show.

VI—The Amplifier Input Stage

The majority of present-day seismic equipment uses a geophone amplifier with an input transformer. This transformer gives an appreciable voltage gain, usually between 15 and 25, and is a reliable and compact unit although having an appreciable weight. The basic circuit is shown in Fig. 7, where the components are detailed, the grid impedance being assumed infinite.

If now we take the geophone output as K volts across the load R, the voltage applied to the grid of the valve (V_G) will be KT for an efficient transformer. The efficiency however depends primarily on the open-circuit inductance of the windings and hence on the transformer size. If we take $w_1L_1 = 2R$ at the lowest frequency of the required pass-band as the criterion, we have a drop of less than 1 db. at this frequency, and a phase change of 27° relative to the centre of the pass-band.

For field use, the transformer size must be limited and the size is primarily determined by the secondary winding. If then we consider this fixed at L_2 henries by weight limitation, we have

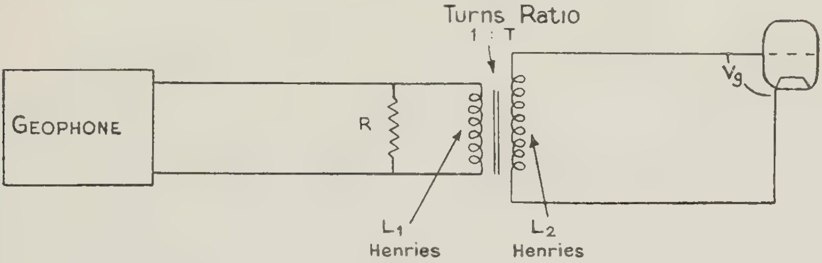


Fig. 7.

$$V_G = KT = K\sqrt{\frac{L_2}{L_1}} = K\sqrt{\frac{L_2w_1}{2R}}$$

Substituting for R, we have

$$V_G = \sqrt{L_2w_1Mhw_0} \qquad (\text{for } w \gg w_0)$$

The effective signal voltage is thus proportional to $(Mw_0)^{1/2}$ and we require a large mass to obtain high sensitivity.

The above analysis must be modified when the geophone resistance and the cable resistance are taken into account. If R_3 is the sum of these resistances the expression becomes

$$V_G = \sqrt{L_2w_1\,Mhw_0\left(\frac{R - R_3}{R}\right)}$$

The ratio of R_3 to R will vary considerably from one equipment to another but we clearly wish to keep R large compared with R_3. Since R is proportional to K^2/M, this implies that an increase in M should be accompanied by an increase of K^2 to maintain R.

In practice, values of R between 500 and 1,000 ohms have been commonly used except in refraction work where R may be higher because of the unavoidable cable resistance. In the latter case R_3 may form as much as 75 %

of R compared with 40 % in reflection equipments. If preamplifiers are used adjacent to the geophone, R_3 may be made small and R may perhaps be reduced below the above figure of 500 ohms.

When using multiple geophones, as is the increasing practice at present, the conditions are rather different. Geophones are then normally connected in series and the damping resistance for each unit will in part be formed by the impedance of the other geophones. In such cases it may well be advisable to damp each geophone individually to about 80 % of the required value, either by coil former damping or its own load resistor, the separately damped units then being connected together. Alternatively, a suitable series-parallel arrangement may be found which will enable the original amplifier impedance to be retained, but this must be largely a matter for trial and error.

VII—Choice of Geophone Natural Frequency

The natural frequency of the geophone will be determined primarily by the frequency response required. If the equipment is required to record ground velocities between a frequency f_1 and a higher frequency f_2, the geophone natural frequency f_0 has an approximate upper limit at f_1 since its response at lower frequencies is much reduced (Fig. 5). If critical damping is required, f_0 will usually be appreciably lower than f_1. Thus a typical reflection equipment may have $f_0 = 30$ c/s and $f_1 = 25$ c/s, the slight drop in response at 25 c/s being tolerable with $h = 0.5$. Later equipments however show more interest in the lower frequencies and with f_1 at 15 c/s, f_0 may be between 5 and 16 c/s. This arises in part from recent tendencies to make equipment more versatile, the earlier low frequency rejection being immediately available through improved filter controls if required.

For field equipments f_0 is usually kept as high as possible in order to give a more robust instrument. During transit, the geophone inevitably suffers shocks and the suspended mass will hit the stops with an appreciable velocity, the repeated impacts tending to distort the springs or cause mechanical failures. Whilst the robustness will be largely a matter of mechanical details, it is also essentially a function of f_0. If we take the case of a geophone dropped on the ground from height H, it is easy to show that the suspended mass hits the stops with velocity v where,

$$v^2 = 2gH - 4\pi^2 f_0^2 x^2,$$ 2x being the separation of the stops.

The following table gives some values for v when $x = 0.5$ cms.

	f_0	80 c/s	30 c/s	20 c/s	5 c/s
H = 1 ft.	v	—	210	235	242 cm/sec.
H = 1 inch.	v	—	—	31	69 ,,

With a 5 c/s geophone, the mass will hit the stops if the geophone is dropped only .05 inches whereas a 30 c/s geophone may be dropped 1.8 inches before contact is made.

The shock may be reduced appreciably by damping the geophone—say by short-circuiting the leads which will usually give a value of h greater than 1. If $h = 1$, the previous figures become .36 inch for the 5 c/s geophone and 13 inches for the 30 c/s geophone. Even this improvement is not sufficient for very low frequency geophones and it has been found in practice that if f_0 is less than 5 c/s it becomes necessary to clamp the suspension during transit.

VIII—Choice of Geophone Mass

In the above discussions no limit has been placed on the value of M, the seismic mass. The effective output of the geophone will be lower if M is small but this could be compensated by an increase in the amplification of the amplifier. It is however essential that the geophone output due to the required signal should stand out clearly above the continuous background from various "noise" sources. These sources have been discussed by Wolf (9) and the following summary is based on his results.

The amplitude of ground unrest is here taken as 10^{-8} cms., a probable minimum value (11), though in many locations it will be considerably higher. Thus in the United Kingdom it is often 10^{-6} cms. or more and the limiting figures for mass given below could be reduced if necessary in an equipment designed to work only in this area. The ground amplitude forming the required seismic signal must clearly be considerably larger than the amplitude of ground unrest.

There are two noise sources in the instrument itself, that formed by the Brownian motion of the suspended mass and that formed by thermal agitation in the resistive components of the geophone circuit. Both these effects can be minimised by a sufficiently large value of M.

It may be shown that the ground motion will be four or five times the Brownian motion—as requried for a clear record, if

$$M \geqslant \frac{840}{f_0^2} \text{ gms.}$$

when $h = 0.7$ and f_0, the natural frequency, is also the lowest frequency to be recorded. This limit will usually only be of interest when f_0 is lower than 7 c/s where the required mass is 17 grams. If f_0 is greater than 7 c/s the geophone coil will usually be heavier than the value given by this expression.

The resistor noise arises in the internal geophone resistance R_i and the external load resistor R_0. Under similar conditions to the above, the limiting mass is given by

$$M \geqslant 267 \frac{f^1 R_i}{f_0^3 R_0} \text{ gms.}$$

where f_1 is the upper frequency limit of the amplifier pass-band. This would give values of M of 835 gms. for a typical refraction equipment and 2 grams for a typical reflection equipment.

Since the noise voltages are additive, these two values of M should be added to give the total mass required. This mass is then sufficient to enable the geophone to detect ground amplitudes of 10^{-8} cms. satisfactorily.

As Wolf has pointed out, in a normal seismic equipment there is also a limit provided by the inherent noise level of the amplifier, arising mainly from valve and transformer noise in the first stage. This may be expressed in terms of the equivalent power input and will depend very much on the filter settings of the amplifier. If we take it to be 0.1×10^{-16} watts., the geophone signal should correspond to 2×10^{-16} watts. for a good record.

This gives a lower limit to the geophone mass of

$$M = \frac{4.5 \times 10^{-11}}{A^2 f_0^3}$$ gms. where f_0 is the lowest frequency to be recorded and A is the amplitude of ground unrest. Taking A to be 10^{-8} cms, this gives a value of 56 gms. for $f_0 = 20$ c/s. If $f_0 = 2$ c/s however, the value becomes 56K gms. which is scarcely practicable. These figures are appreciably higher than those given above for the geophone noise sources and this limit is therefore the effective design limit.

These limits are of course for ideal systems and they may well have to be raised because of unavoidable losses in the geophone. There will also be a certain amount of noise developed in the geophone cables though this is a most variable quantity. On the other hand, the ground amplitude of 10^{-8} cms. used in these calculations is probably a rather uncommon minimum and a value of 10^{-7} cms. may be sufficient for most areas. It may often be more convenient to increase the induced ground motion, i.e. to increase the dynamite charge, than to obtain the higher sensitivity by increase of geophone mass.

IX—Conclusion

An attempt has been made in this paper to outline the relevant theoretical considerations in the design of an electromagnetic geophone. It is clear from what has been said that the designer must essentially be given the frequency pass-band required and also the degree of damping required, though the theoretical and mechanical aspects of the design become interwoven. Thus, in order to give increased versatility, the pass-band is usually required to be as wide as possible: the designer must then compromise between a good low frequency response and a highly portable geophone.

In the previous discussion, it has been implicitly assumed that the most desirable form of geophone frequency response is a constant voltage output for constant ground velocity, this being the basic response of an electromagnetic geophone. Using different forms of geophone however, one may instead obtain voltage outputs which are constant for either constant ground displacement or constant acceleration.

The frequency response of the 'ideal' electromagnetic geophone may be plotted for these types of ground motion and Fig. 8 shows the responses for the three types of input. Using different types of geophone, curves similar to (b) may be obtained for any of the three types of input. As an example of the apparent change produced by the drawing of the graph, curve (d) shows the response of the geophone of Fig. 5 redrawn for a constant displacement input. It is clear that it then has approximately a constant voltage output and might, for certain applications, be preferred therefore to the more usual geophone.

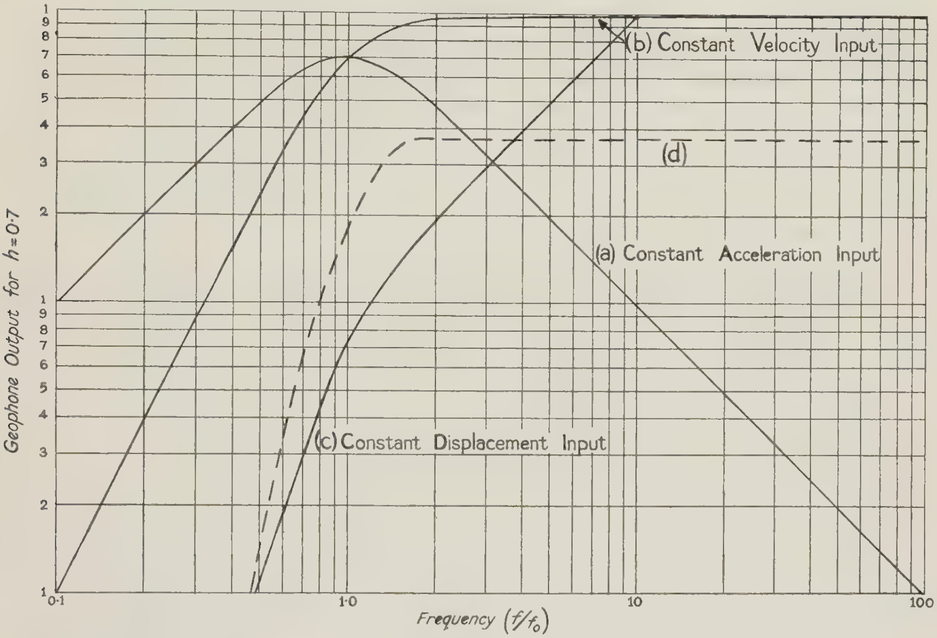


Fig. 8.

Considerations of portability and convenience apart, the choice between the possible types of frequency response must depend on the nature of the seismic impulses to be recorded and of their relation to the noise background. However, in view of the research still to be carried out on the form of the seismic impulses, this approach to the problem must be regarded as a hope for the future rather than a present possibility. In the meantime, the electromagnetic geophone is a convenient and efficient instrument for seismic detection and one which has reached a high state of mechanical development.

ACKNOWLEDGEMENTS

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SOME REMARKS ON THE INTERPRETATION OF GRAVITATIONAL AND MAGNETIC ANOMALIES *

BY

KARL JUNG **

Abstract

Two geometric methods are given: one for estimating the position of mass distributions from the gravity anomalies, the other for determining the position of a thin plate of magnetized material from the magnetic anomalies. Finally a computational form of Nettleton's method for the determination of density is given.

I—A Simple Geometric Method for Estimating the Position of Mass Distributions from their Gravity Anomalies

As a first step of interpretation of gravity anomalies it is often allowed to approximate the mass distribution by a "two dimensional" surface layer with linear cross section AB (Fig. 1).

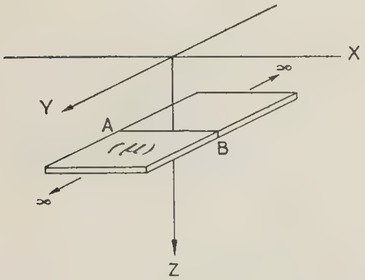

Fig. 1.

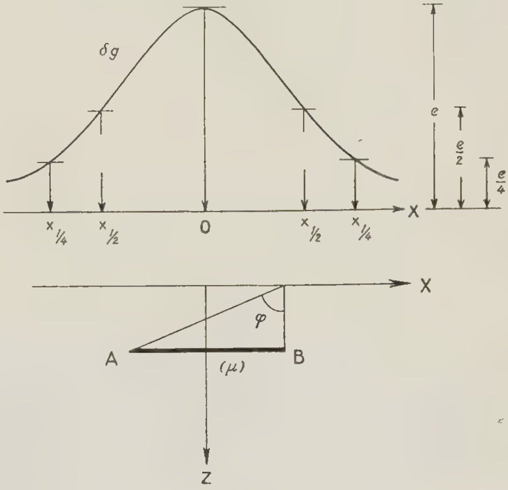

Fig. 2.

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* Presented at the London Meeting of the European Association of Exploration Geophysicists, May 22/23, 1952.

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It is well known that its gravity anomaly is (Fig. 2):

$$\delta g = 2\,k\mu\phi$$

δg = gravity anomaly
k = gravitational constant
μ = surface density (constant)
ϕ = angle of vision

From this relation a very simple geometric method of determining A and B is derived (Fig. 3):

A circle is drawn with O for centre and $x_{\frac{1}{2}}\,x_{\frac{1}{2}}$ for diameter, and a circle with M for centre and with $Mx_{\frac{1}{4}}$ for radius. A and B are the intersections of both circles.

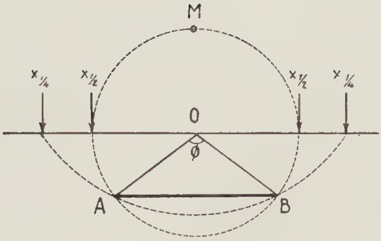

Fig. 3.

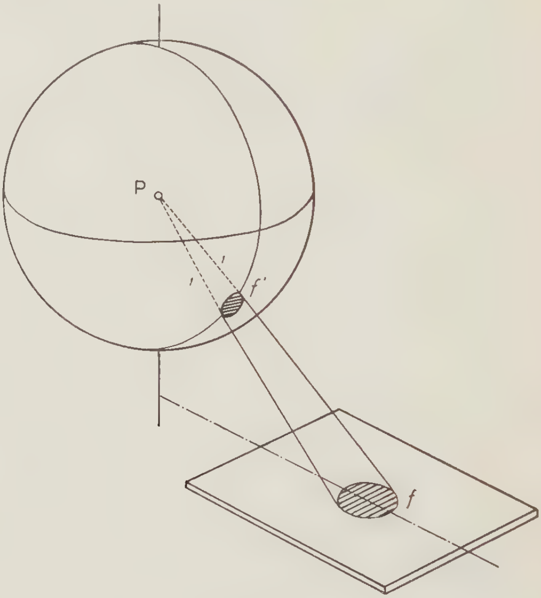

Fig. 4.

Then μ may be computed by

$$\mu = \frac{e}{2\,k\,\Phi}$$

$$|e| = |\delta g|_{\max}$$

$$\Phi = \angle\, AOB, \text{ taken from Fig. 3.}$$

The principle formula $\delta g = 2k\mu\phi$ and many other useful relations may be derived from the theorem that in P (Fig. 4)

$$\delta g = k\mu f'$$

f' = projection of the surface element f on the sphere, with radius 1 round P (solid angle of f)
μ = surface density of f
k = gravitational constant

II—A Geometric Method for Determining the Position of a Thin Plate of Magnetized Material from its $\triangle Z$- and $\triangle H$-anomalies

A magnetized dyke may often be approximated by a "two dimensional" inclined plane. Its vertical cross section in the ξ-direction is shown in Fig. 5.

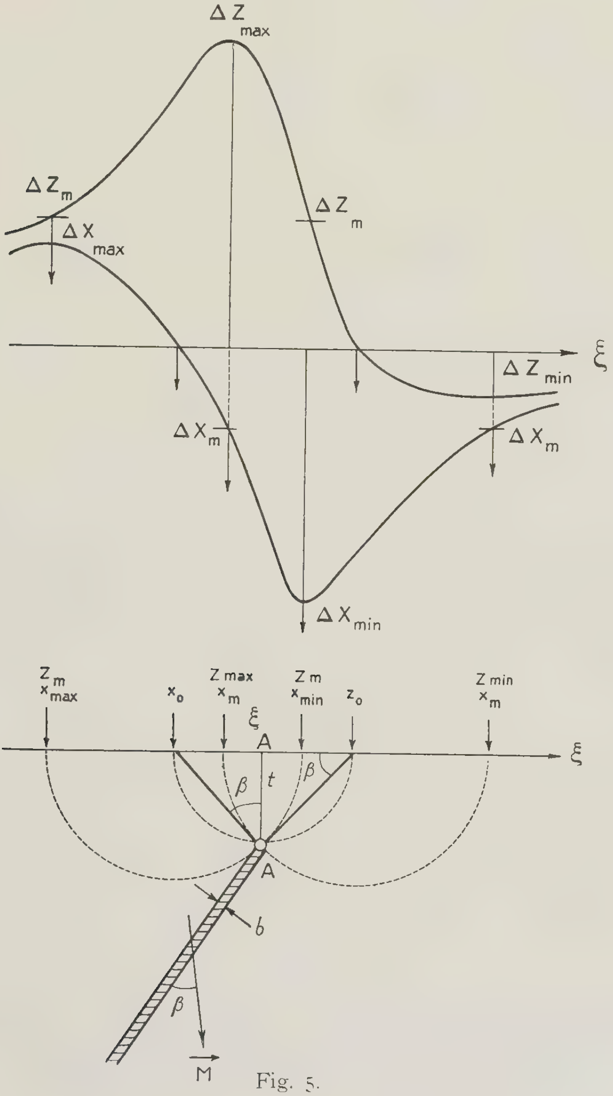

Fig. 5.

$\triangle Z$ = anomaly of vertical intensity

$\triangle X$ = anomaly of horizontal intensity, perpendicular to the bearing of the dyke [$\triangle H$ is the northern component of $\triangle X$]

$$\left.\begin{array}{l}\triangle Z_{max},\ \triangle Z_{min}\\ \triangle X_{max},\ \triangle X_{min}\end{array}\right\} = \text{maxima and minima of } \triangle Z \text{ and } \triangle X$$

$$\left.\begin{array}{l}\triangle Z_m = \dfrac{\triangle Z_{max} + \triangle Z_{min}}{2}\\[2ex] \triangle X_m = \dfrac{\triangle X_{max} + \triangle X_{min}}{2}\end{array}\right\} = \text{arithmetic means}$$

Z_{max}, Z_{min}, Z_m = abscissae of $\triangle Z_{maz}$, $\triangle Z_{min}$, $\triangle Z_m$

X_{max}, X_{min}, X_m = abscissae of $\triangle X_{maz}$, $\triangle X_{min}$, $\triangle X_m$

$Z_o = \xi_{\triangle Z = o}$

$X_o = \xi_{\triangle X = o}$

$\vec{M}$ = profile component of homogeneous magnetization

$\beta = \angle\ (\text{dip}, \vec{M})$

A = headpoint ("Kopfpunkt") of the cross section

ξ = abscissa of A

t = depth of A

$b \ll t$

Roessiger has proved that all homogeneous plane distributions with the same headpoint A and the same angle β (Fig. 6) excite exactly the same magnetic anomaly. Therefore it is impossible to compute the directions of dip and of $\vec{M}$ separately.

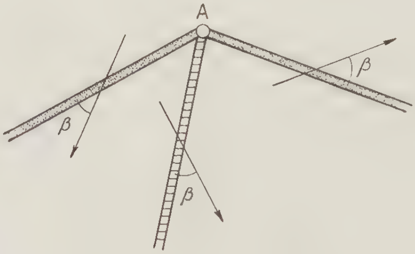

Fig. 6.

It is only possible to determine the angle β, if one has no other instructions than the magnetic anomalies.

In the usual manner one gets

$$\Delta Z = \frac{2\,|\vec{M}|\,b}{t} \cdot \frac{-\frac{\xi - \xi_A}{t}\sin\beta + \cos\beta}{1 + \left(\frac{\xi - \xi_A}{t}\right)^2}$$

$$\Delta X = -\frac{2\,|\vec{M}|\,b}{t} \cdot \frac{\sin\beta + \frac{\xi - \xi_A}{t}\cos\beta}{1 + \left(\frac{\xi - \xi_A}{t}\right)^2}.$$

From these formulae some relations are derived useful for proving whether the approximation by a plane distribution is allowed.

$$\Delta Z_{max} - \Delta Z_{min} = \Delta X_{max} - \Delta X_{min}$$

$$X_m = \begin{cases} Z_{max} \\ Z_{min} \end{cases}$$

$$Z_m = \begin{cases} X_{max} \\ X_{min} \end{cases}$$

$$Z_0 = \frac{Z_{max} + Z_{min}}{2}$$

$$X_0 = \frac{X_{max} + X_{min}}{2}$$

X_{max}, Z_{max}, X_{min}, Z_{min} are harmonic points.

There are three circles which intersect in the headpoint A:

the circle with the centre X_0 and the diameter $X_{max}\ X_{min}$ $[Z_mZ_m]$,

the circle with the centre Z_0 and the diameter $Z_{max}\ Z_{min}$ $[X_mX_m]$,

the circle with the diameter $X_0\ Z_0$

Practically these circles do not intersect exactly in one point, but form a little triangle, the centre of which may be taken as headpoint A. Shape and size of the triangle are criteria for the exactness of the results.

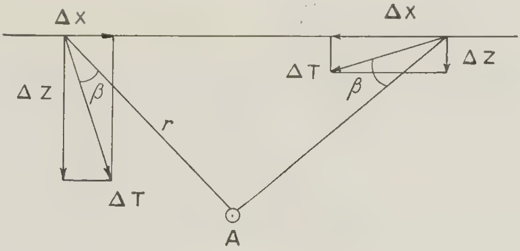

Fig. 7.

The angle β is to be found between Az_0 and the horizontal surface or between Ax_0 and $A\xi_A$.

In every point of the plain surface the radius vector r and the vector of total anomaly $\triangle T$ form the same angle β (Fig. 7).

III—A COMPUTATIONAL FORM OF NETTLETON'S METHOD FOR THE DETERMINATION OF DENSITY

In order to determine the underground density, Nettleton takes gravity values measured at stations in different heights, and computes the Bouguer reductions several times, assuming different densities. Thus he gets several gravity distributions more or less related to surface heights in both positive or negative sense. The density belonging to the distribution with the least relation to surface heights is held to be true.

Regarding that the correlation coefficient k of the Bouguer anomalies $\triangle g''$ and surface heights h is zero,

$$k\,(\triangle g'', h) = \frac{\Sigma(\triangle g'' - M(\triangle g''))\,(h - M(h))}{\sqrt{\Sigma(\triangle g'' - M(\triangle g''))^2 \,.\, \Sigma(h - M(h))^2}} = 0$$

$$\left.\begin{matrix} M(\triangle g'') \\ M(h) \end{matrix}\right) \text{ arithmetic means of } \begin{matrix} \triangle g'' \\ h \end{matrix},$$

it is possible to express Nettleton's method in a mathematical manner and to derive a system of simple formulae leading directly to the best density value. One gets without difficulty

$\triangle g_1'' = (g - \gamma_0) + (0.3085 - 0.04193\,\sigma_1)\,h$

$= \text{Bouguer anomaly with (approximated) density } \sigma_1$

$G \quad = \triangle g_1'' - M(\triangle g_1'')$

$H \quad = h - M(h)$

$$a = \frac{\Sigma\, GH}{\Sigma\, H^2}$$

$$\sigma_2 = \frac{a}{0.04193}$$

$\sigma \quad = \sigma_1 + \sigma_2 =$ best density value.

It is well known that Nettleton's method is not applicable, if there is a linear relation of $\triangle g''$ and h. Then the computational form also is useless.

A good criterion $\delta\sigma$ for the exactness of σ may be computed in the following way:

$$F^2 = \frac{\Sigma\,(G - aH)^2\, H^2}{\Sigma\,(G - aH)^2 \,.\, \Sigma\, H^2}$$

$$(\delta\, a)^2 = a^2 - \left(\frac{a^2}{1 - F^2} - \frac{F^2}{1 - F^2} \cdot \frac{\Sigma\, G^2}{\Sigma\, H^2}\right)$$

$$\delta\,\sigma = \pm\,\frac{|\,\delta\, a\,|}{0.04193}$$

F is the standard error of k ($\triangle g''$, h), but δa and $\delta\sigma$ are not the standard errors of a and σ.

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DISCUSSION

Mr. KUNZ: This method of density determination is very useful in flat country but it is dangerous if the regional anomaly follows the surface elevations.

Mr. JUNG: Good results have been obtained in the Harz Mountains with this method. If there is correlation between gravity values and surface elevations then neither this method nor Nettleton's can be used.

Mr. VENING MEINESZ: In computing the Bouguer anomaly the isostatic compensation is ignored. In large areas better results might be achieved by applying the complete isostatic reduction.

Mr. JUNG: I agree.

Mr. SCHLEUSENER: Sometimes the density varies over short distances with only small height changes and this would make the method difficult to use.

Mr. JUNG: There are good and bad areas. Generally, if Nettleton's method is useful, this one is even more satisfactory.

Mr. BARANOV: If only small heights are involved there is no need for precise determination of the density. The magnetic field of a vein is shaped like that of an ordinary magnet and because of its symmetry the location of the vein can be determined.

SUR LE CALCUL DE L'INFLUENCE GRAVIMETRIQUE DES STRUCTURES DEFINIES PAR LES ISOBATHES [*]

Application à la correction topographique

PAR

V. BARANOV [**]

Abstract

The triple integral for the attraction of a mass on a point is transformed in a double sum. This double sum serves to construct a graph for the rapid determination of the gravimetric influence of structures given by depth contours. The influence of topography can also be computed with this graph.

Le calcul de l'influence gravimétrique n'est relativement simple que dans le cas des structures dites cylindriques ou à deux dimensions. Cette simplicité tient surtout au fait qu'une structure à deux dimensions ne demande qu'une coupe unique pour être complètement définie, et cette coupe est la même quelle que soit la station considérée.

Dans le cas général la représentation par les coupes ne convient pas. La seule façon commode de représenter le terrain, dans le cas général, consiste à tracer les courbes de niveau ou les isobathes. Il est donc souhaitable de pouvoir calculer l'attraction en utilisant directement la carte des isobathes, sans passer par l'intermédiaire des coupes.

D'autre part, les abaques dont on se sert habituellement nécessitent un comptage des mailles ou des points. C'est une opération fastidieuse conduisant à des erreurs et qui n'est pas susceptible d'une précision désirable.

C'est pourquoi nous avons étudié une méthode de calcul un peu différente. En usage à la Compagnie Générale de Géophysique depuis plusieurs années déjà, elle s'est révélée très souple, plus précise que les méthodes courantes et plus rapide.

La composante verticale de l'attraction d'un corps de densité σ s'exprime à l'origine des coordonnées polaires (σ, ρ, ω, z) par l'intégrale triple

$$g = z\,\sigma \iiint \frac{\rho\, z\, d\rho\, dz\, d\omega}{(\rho^2 + z^2)^{3/2}}$$

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[*] Presented at the Hague Meeting of the European Association of Exploration Geophysicists Dec. 15, 1951.

[**] Compagnie Générale de Géophysique.

Nous allons effectuer l'intégration en deux temps. Intégrons d'abord par rapport à ρ et z en posant

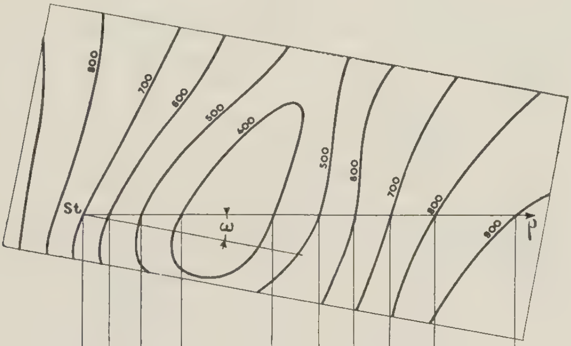
$$\varphi(\omega) = 2\,k\pi \int\int \frac{z\rho\,dz\,d\rho}{(\rho^2 + z^2)^{3/2}}$$

ensuite, par rapport à

$$g = \sigma \cdot \frac{1}{2\pi} \int_0^{2\pi} \varphi(\omega)\,d\omega$$

L'intégrale double $\varphi(\omega)$ est étendue à l'aire d'une coupe verticale du terrain suivant l'azimut ω. Nous avons représenté une telle coupe sur la fig. 2 construite à partir des isobathes de la fig. 1, mais nous répétons que la construction effective, comme on va voir, n'est pas nécessaire.

Fig. 1



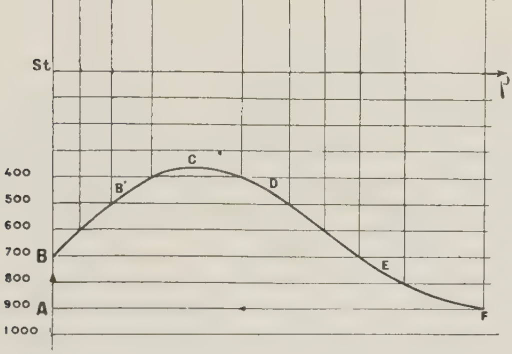


Fig. 2.

Intégrons d'abord par rapport à ρ pour une valeur constante de z. L'intégrale indéfinie est

$$\int \frac{\rho\,d\rho}{(\rho^2 + z^2)^{3/2}} = \frac{1}{z} - \frac{1}{\sqrt{\rho^2 + z^2}} + \text{Cte}$$

Donc,

$$\varphi(\omega) = 2\,k\pi \int \left(1 - \frac{z}{\sqrt{\rho_1^2 + z^2}}\right) dz - 2\,k\pi \int \left(1 - \frac{z}{\sqrt{\rho_2^2 + z^2}}\right) dz$$

Ici ρ_1 et ρ_2 sont deux fonctions de z-limites de l'intégration par rapport à ρ.

Il est plus simple d'ailleurs de mettre l'expression de $\varphi(\omega)$ sous forme d'une intégrale curviligne

$$\varphi(\omega) = 2\,k\pi \oint \left(1 - \frac{z}{\sqrt{\rho^2 + z^2}}\right) dz$$

prise le long du contour de la coupe représentée sur la fig. 2. Il est évident que cette coupe peut être limitée par n'importe quel plan horizontal AF de cote $z = h =$ Cte. En effet, en modifiant cette cote fixe et la même pour toutes les stations, on ajoute partout une même constante à la valeur de g, et l'anomalie gravimétrique reste, par conséquent, inchangée.

Posons maintenant

$$u = 250\,.\,k\pi \left(1 - \frac{z}{\sqrt{\rho^2 + z^2}}\right)$$

Le coefficient numérique 250 est introduit ici uniquement pour la commodité; il ne joue aucun rôle essentiel.

Nous avons maintenant

$$\varphi(\omega) = \frac{1}{125} \oint u(z)\,.\,dz$$

Avant de chercher une valeur approchée de cette intégrale, voyons quelle est sa signification géométrique. Construisons une courbe fermée en portant z en abscisses et u en ordonnées. La fig. 3 en donne un exemple. La courbe ABCDEF correspond à la coupe de la fig. 2. Alors, la valeur de l'intégrale n'est autre chose que l'aire de cette courbe. La coupe du terrain est limitée par un plan AF de cote „900". La droite verticale AF de la fig. 3 correspond à ce plan et limite l'aire de la courbe u (z).

Pour évaluer cette aire, le plus simple est de remplacer la courbe ABCDEF par un contour polygonal et d'admettre que la valeur de l'intégrale est égale à la somme des aires des trapèzes dont chacun est limité par deux côtés du contour et par deux segments verticaux. La fig. 4 montre l'un de ces trapèzes. Son aire est égale à

$$\Delta S = \frac{\Delta z}{2} (u_1 - u'_1 + u_2 - u'_2)$$

Naturellement, on prendra pour tous les trapèzes la même hauteur Δz (c'est l'équidistance des isobathes) que l'on mettra en facteur. En ce qui concerne le coefficient ½ il disparaîtra lorsqu'on fera la somme des aires, car chaque base est commune en général à deux trapèzes et intervient, par conséquent, deux fois. LA seule exception est le segment AF qui ne limite qu'un seul trapèze. Mais même pour ce segment, il est inutile de garder ce facteur. En effet, le supprimer revient à prendre $h + \frac{1}{2} \Delta z$ pour la cote du plan de base au lieu de h. Dans notre exemple 950 m. au lieu de 900 m. Ceci ne modifie évidemment pas l'anomalie gravimétrique, à condition de garder le même plan de base pour toutes les stations.

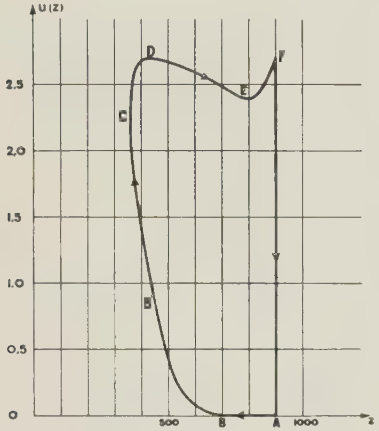


Fig. 3.

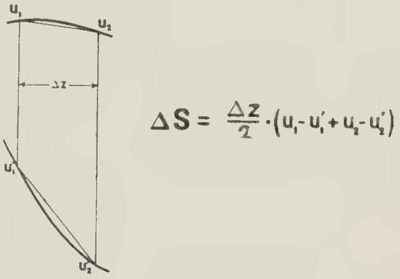


Fig. 4.

Nous obtenons finalement la formule

$$\varphi\,(\omega) = \frac{\Delta\,z}{125} \sum u$$

mais il est entendu que la somme est algébrique : il faut affecter u du signe + chaque fois que l'on sort du terrain (points D, E, ...) et du signe — chaque fois que le rayon-vecteur $O\rho$ s'enfonce dans le terrain (points B, B', ...).

Ainsi, $\varphi\,(\omega)$ étant calculé, il nous reste à intégrer par rapport à ω. Or, remarquons que l'intégrale

$$\frac{1}{2\,\pi} \int_0^{2\,\pi} \varphi\,(\omega)\, d\,\omega$$

est la valeur moyenne de la fonction $\varphi\,(\omega)$. Si donc nous considérons n azimuts régulièrement répartis, l'intégrale en question sera approximativement égale à

$$\frac{1}{n} \cdot \sum \varphi\,(\omega)$$

Donc,

$$g = \frac{\sigma}{n} \sum \varphi\,(\omega)$$

En portant ici la valeur de $\varphi(\omega)$ que nous avons déjà trouvée, on obtient l'expression définitive

$$g = \sigma \cdot \frac{8}{n} \cdot \frac{\Delta z}{1000} \sum \sum u$$

Le facteur 8/n a été mis en évidence parce que la valeur $n = 8$ est commode: huit azimuts donnent une précision très suffisante. Le facteur 8/n est alors égal à un et peut être supprimé.

Le calcul de l'attraction revient ainsi à relever les valeurs de u et à calculer leur somme algébrique. La double somme se rapporte d'une part aux azimuts et d'autre part aux intersections des azimuts avec les isobathes.

Il est très facile de relever les valeur de u directement sur la carte des isobathes à l'aide d'un abaque qui a la forme d'un rapporteur.

Si l'équidistance Δz des isobathes est exprimée en mètres et si l'on veut exprimer g en milligals, il faut prendre $k = 1/150$ pour la constante de gravitation. Alors, on aura

$$u = 5{,}236 \cdot \left(1 - \frac{z}{\sqrt{\rho^2 + z^2}}\right)$$

Donnons à z une valeur constante correspondant à une courbe de niveau. Alors, ρ sera une fonction de u:

$$\rho = z \sqrt{\frac{1}{(1 - 0{,}191 \cdot u)^2} - 1}$$

et nous pouvons construire un diagramme en coordonnées polaires en considérant u comme une quantité proportionnelle à l'angle polaire. Alors, la valeur de ρ sera égale à la longueur du rayon-vecteur entre 'origine et un point de la courbe $z =$ Cte. Evidemment, il faut construire une famille de courbes homothétiques pour les différentes valeurs de z.

Si l'échelle de ce diagramme est la même que celle de la carte des isobathes utilisée, on peut superposer les deux dessins en faisant coïncider les rayons-vecteurs ρ. On obtiendra la valeur de u par un simple relevé sur une échelle circulaire.

Considérons la fig. 5. La courbe $z =$ Cte tracée en traits fins est une isobathe de la carte. La droite SM est un des azimuth considérés. Les spirales tracées en gros traits sont les courbes du diagramme. Orientons l'ensemble de façon à ce que l'origine S se trouve en coïncidence avec la station et que la spirale $z =$ Cte passe par le point M—intersection de l'isobathe avec l'azimut. Alors, la valeur de u correspondant au point M s'obtient par une lecture sur l'échelle circilaire, l'azimut servant d'index. Il ne reste qu'à faire la somme algébrique des u et à la multiplier par $0{,}001 . \Delta z$ et par σ.

Une dernière remarque concernant l'échelle de la carte. Les valeurs de u ne dépendent que du rapport ρ/z. Par conséquent, si l'échelle de la carte se trouve modifiée dans un rapport λ, nous mesurons la longueur $\lambda\rho$ au lieu de

ρ et la même valeur de u correspond à l'isobathe cotée λz au lieu de z. Il en résulte que pour se servir de l'abaque, il faut d'abord étalonner les spirales homothétiques. Autrement dit, il faut attribuer à chaque courbe une cote z. A cet effet, il suffit de remarquer que pour la valeur $u = 1{,}5335$, l'égalité $\rho = z$ se trouve réalisée. Si donc on trace sur l'abaque une demi-droite SE correspondant à $u = 1{,}5335$, les cotes des spirales seront égales aux distances ρ des spirales comptées le long de cette demi-droite et lues à l'échelle de la carte.

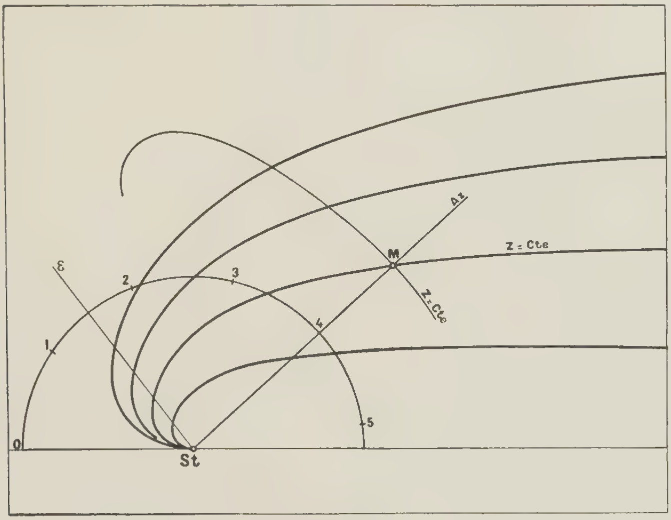


Fig. 5.

Pratiquement, le „rapporteur" avec les spirales et l'échelle des u est fait en matière plastique transparente. A l'origine est percé un petit trou par lequel peut passer une aiguille réalisant l'axe de rotation. L'aiguille est piquée au point de la carte où on veut calculer l'attraction. On trouvera ici un modèle plus simple (fig. 6). Il est un peu moins précis et moins commode que le rapporteur original.

Pour terminer, ajoutons encore quelques mots au sujet du calcul de la correction topographique.

Le problème est le même que tout-à-l'heure. Il s'agit de calculer la composante verticale de l'attraction des masses superficielles définies par les courbes de niveau et limitées par le plan horizontal passant par la station. Le même procédé de calcul est donc applicable et le principe de la méthode est le même. Au point de vue pratique la différence réside dans le fait que la précision exigée est plus grande et que l'équidistance des courbes de niveau est plus faible.

Nous avons construit un rapporteur spécial pour cet usage. La fig. 7 représente un modèle qui nous sert pour la correction au voisinage immédiat de la station jusqu'à 230 m., c'est-à-dire, pour les zones A à C2 de Hayford. L'échelle

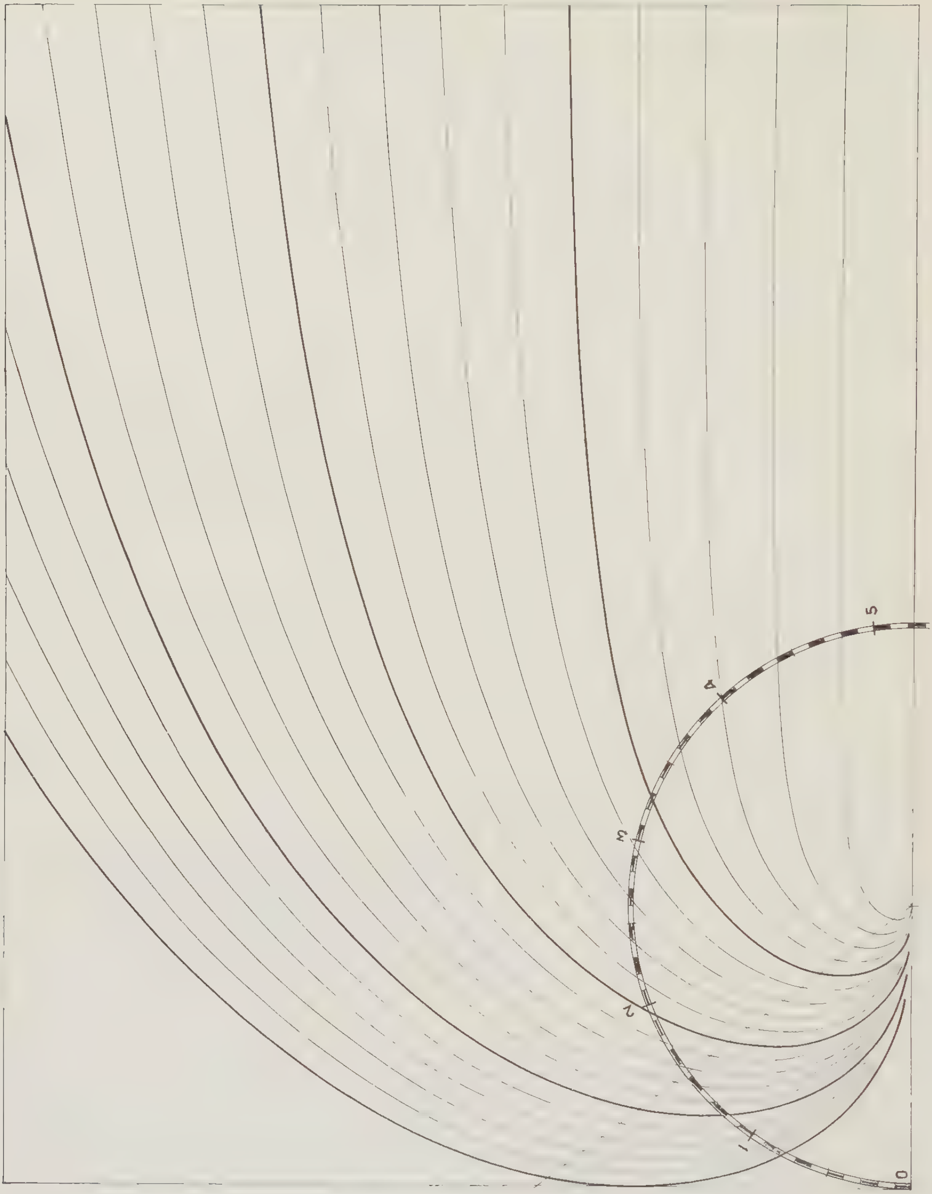


Fig. 6.

choisie une fois pour toutes est de 1 : 2000. Il y a deux séries de spirales avec l'équidistance de 5 m. et de 1 m. A chaque série correspond une échelle des u. La troisième échelle (intermédiaire) correspond à la courbe z = 5 m.

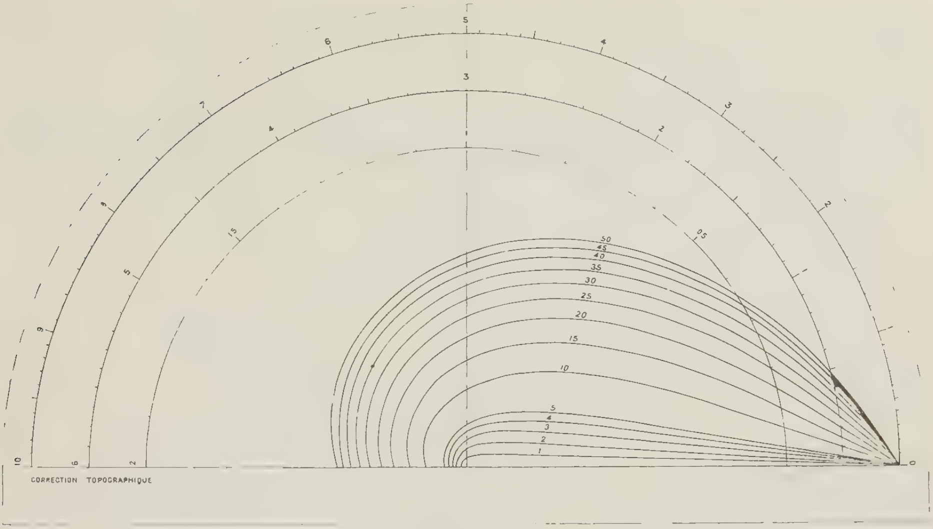


Fig. 7.

Les valeurs de u sont données cette fois par la formule

$$u = 1250 \, . \, k\pi \left\{ \frac{z}{\sqrt{R^2 + z^2}} - \frac{z}{\sqrt{R^2 + z^2}} \right\}$$

avec $R = 230$ m.

La correction topographique est

$$g = \sigma \, . \, \frac{8}{n} \, . \, \frac{\Sigma\Sigma\, u}{1000}$$

où σ est la densité des terrains superficiels.

Discussion

Mr. Scheen : La question que je voudrais poser concerne un point de détail. Si l'on veut évaluer l'intégrale par rapport à z, on pourrait imaginer qu'un diagramme soit construit, montrant les valeurs de la quantité u en fonction de z. Alors il faut calculer l'aire de ce diagramme. Il paraît que cette méthode exige une addition des segments comme vous l'avez indiqué. Pourtant, le dernier segment n'entre dans le calcul qu'à moitié. Quant à ce point vous avez remarqué que si l'on fait le calcul comptant le dernier segment entièrement, on ajoute à la structure une couche d'une certaine épaisseur qui est constante pour toutes les stations. Comme on s'intéresse seulement aux différences des valeurs du g, on verrait que cette façon d'agir est justifiée. Mais ne faut-il pas aussi qu'on soit sûr que le rayon de cette couche supplémentaire soit également identique pour toutes les stations ?

Mr. Baranov : Prenez la profondeur telle que le rayon devienne très grand ou prâtiquement infini.

UNE REGLE POUR LES CALCULS DE SISMIQUE-REFRACTION *

PAR

JEAN GOGUEL **

ABSTRACT

A ruler has been constructed to solve seismic refraction problems with horizontal or slightly/inclined layers.

Le calcul des épaisseurs des couches successives, dans l'hypothèse où elles sont horizontales, joue un rôle essentiel en sismique réfraction, soit que cette approximation soit suffisante, soit que les vitesses lues sur le diagramme dromochrônique aient été corrigées, par comparaison entre les tirs directs et inverses, pour tenir compte d'un faible pendage.

On sait que, si la dromochrônique est tracée sous la forme d'une ligne polygonale, la pente de chaque côté est l'inverse de la vitesse dans la couche pour laquelle le rayon sonore correspondant s'est propagé horizontalement ; on peut donc lire immédiatement sur le diagramme, à l'aide d'un rapporteur approprié, cette vitesse. D'autre part, on a l'habitude de caractériser chacun de ces côtés par l'ordonnée de son intersection avec l'axe des temps, qui représente le retard de l'onde par rapport au temps qu'elle aurait mis si elle s'était propagée sur tout le parcours à la même vitesse que dans la couche la plus profonde qu'elle ait atteinte.

Pour une couche caractérisée par une vitesse V_i et d'épaisseur h_i nous poserons :

$$\tau_i = h_i/V_i$$

τ_i indique la durée de parcours d'une onde traversant normalement la couche. On sait que l'onde sonore qui se propage horizontalement dans la couche à vitesse V_n fait avec la verticale dans la couche de vitesse V_i un angle A^i_n tel que :

$$\sin A^i_n = V_i/V_n$$

Calculons séparément pour cette couche la différence entre la durée réelle du parcours suivant M N (fig. 1), et le temps qui aurait été nécessaire pour franchir à la vitesse V_n la projection horizontale M N soit M′ N. Le principe de Huygens permettrait de construire le rayon réfracté, et montre immédiatement que le temps nécessaire pour franchir M′ N à la vitesse V_n est égale au temps mis pour parcourir effectivement la longueur H M, H étant le pied de la perpendiculaire abaissée de M′ sur le rayon sonore M N. Il en résulte immédiatement que le retard est égal à la durée de parcours de la longueur M H, soit τ_i x cos. A. On déduit immédiatement de là les valeurs de l'ordonnée à l'origine, pour les côtés successifs de la ligne polygonale, correspondants aux rayons se réfractant horizontalement dans les couches d'indices successifs :

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* Presented at the London Meeting of the European Association of Exploration Geophysicists, May 22/23, 1952.

** Bureau des Recherches Géologiques et Géophysiques.

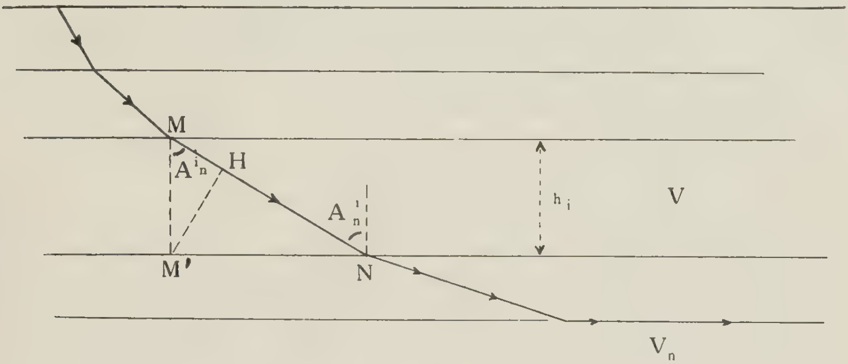

Fig. 1.

$$\left\{\begin{array}{l} \frac{1}{2}t_1 = \cos A^0{}_1\, \tau_0 \\ \frac{1}{2}t_2 = \cos A^0{}_2\, \tau_0 + \cos A^1{}_2\, \tau_1 \\ \frac{1}{2}t_n = \cos A^0{}_n\, \tau_0 + \cos A^1{}_n\, \tau_1 + \ldots + \cos A_n{}^{n-1}\, \tau_{n-1} \end{array}\right.$$

Pour faciliter la résolution de ce système d'équation, on peut utiliser un petit appareil qui est représenté par la figure 2 ; et sur lequel on lit immédiatement les valeurs de tous les coefficients. Dans cet appareil, l'échelle du bas est une échelle logarithmique des vitesses. Chacune des réglettes mobiles, qui correspondent aux couches successives comporte un index que l'on place en regard de la vitesse correspondante, et une graduation qui donne directement la valeur du cosinus, au point dont l'abcisse est le logarithme du sinus. Les index indiquent donc sur les réglettes les valeurs des coefficients du système ci-dessus, qui se résoud immédiatement par récurence. Pour gagner du temps, il y a intérêt, aussitôt l'une des inconnues τ_{n-1} calculée, en divisant par son coefficient la différence $(\frac{1}{2}t_n - \Sigma_1{}^{n-1} \cos A^i{}_n\, \tau_i)$ à porter immédiatement dans les équations suivantes, les valeurs des produits de cette inconnue par les coefficients correspondants. Ceux-ci se lisent sur les réglettes successives le long du même index, et ces produits, si l'on travaille avec une règle à calcul, se lisent directement, sans déplacer la réglette.

Conduit de cette manière, le calcul devient extrêmement rapide, même pour un nombre de couches relativement élevé. Mais le gain de temps n'est pas le seul avantage de l'appareil décrit. Le fait que le calcul soit rapide permet de le répéter un grand nombre de fois, et par conséquent, d'aborder d'une manière plus complète la discussion des différentes manières dont on peut parfois interpréter une dromochrone. Il règne souvent une certaine indétermination dans la manière dont on trace, par les points expérimentaux, les côtés successifs de la ligne polygonale. La seule manière d'éviter l'incertitude résultant de cette indétermination, ou tout au moins de se rendre compte exactement de son influence, est de recommencer le calcul pour les différentes hypothèses possibles. Lorsque, dans les terrains superficiels altérés, la vitesse augmente d'une manière plus ou moins progressive, on pourra distinguer dans les terrains superficiels un nombre de couches aussi élevées que cela sera nécessaire, d'ailleurs sans leur attacher aucune signification physique, sans pour cela rendre inabordable le calcul des épaisseurs des couches les plus profondes.

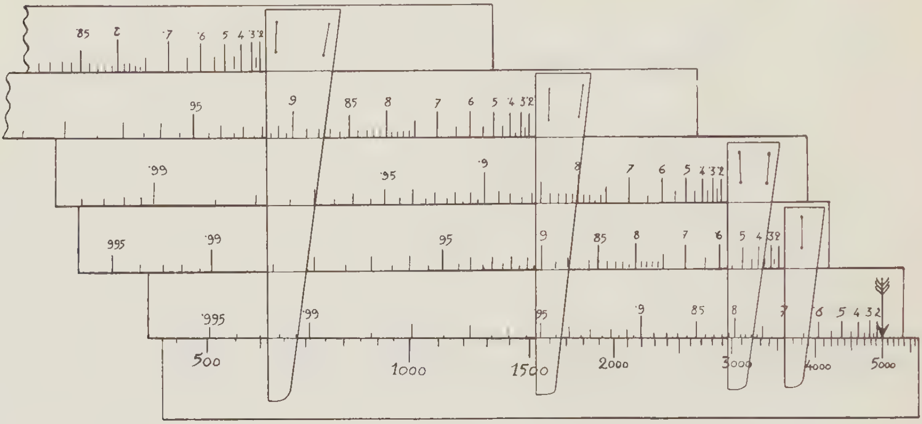

Fig. 2.

Si l'on a une raison quelconque de soupçonner l'existence d'une couche, à vitesse intermédiaire entre ses voisines, mais trop peu épaisse pour donner lieu à un côté de la ligne polygonale, la manière la plus simple d'estimer son épaisseur maxima consiste à refaire le calcul, comme si le segment correspond de la dromochrônique passait par le point d'intersection des deux côtés représentant l'arrivée des ondes réfractées dans les couches voisines, et ceci pour les différentes valeurs possibles de la vitesse. Par des tâtonnements successifs, on peut ainsi se rendre compte de la marge d'incertitude qui peut affecter les résultats obtenus par l'application brutale à la dromochrône des méthodes de calcul classique. Il est indispensable de conduire une telle discussion d'une manière approfondie car on sait que le résultat de toute mesure physique doit s'exprimer non seulement par un nombre, mais par l'indication de l'erreur qui peut affecter les résultats.

Dans une prospection effectuée dans une région alpine, il s'agissait de fixer, sous un recouvrement d'alluvions, le tracé d'une vallée ancienne, remblayée par des alluvions. Un premier profil sismique avait indiqué les vitesses successives de 600, 1500, 3000 et 5000 m/sec. avec respectivement des épaisseurs de 3 m, 40 m et 55 m ; (la dromochrône est indiquée en traits interrompus sur la ligne 3) ; la comparaison avec un sondage mécanique voisin avait permis de conclure que la couche à 3000 m/sec. représentait des alluvions consolidés et devenus particulièrement compacts. Le bed-rock correspondait à la couche à 5000 m/sec. avec une profondeur de 98 m.

Un peu plus en aval, la dromochrônique (en traits pleins) indiquait seulement, selon la méthode classique d'interprétation, des alluvions à 600 et 1500 m/sec., reposant sur le bed-rock à 5000 m/sec. à 77 m, soit à une cote nettement plus élevée que la cote trouvée plus en amont. Fallait-il conclure à un surcreusement de la vallée, dont le profil longitudinal n'aurait pas présenté une pente régulière ? En supposant l'existence d'une couche à 3000 m/sec., d'une épaisseur telle que le côté correspondant à la dromochrônique n'aurait pas donné lieu à la première arrivée d'une onde, mais aurait passé simplement par le point d'intersection des côtés relatifs aux vitesses de 1500 m/sec. et de 5000 m/sec., (tracé en trait mixte, figure 3) on trouve que la profondeur du bed-rock pourrait atteindre 102 m, d'où une cote qui pourrait être inférieure à celle trouvée plus en amont.

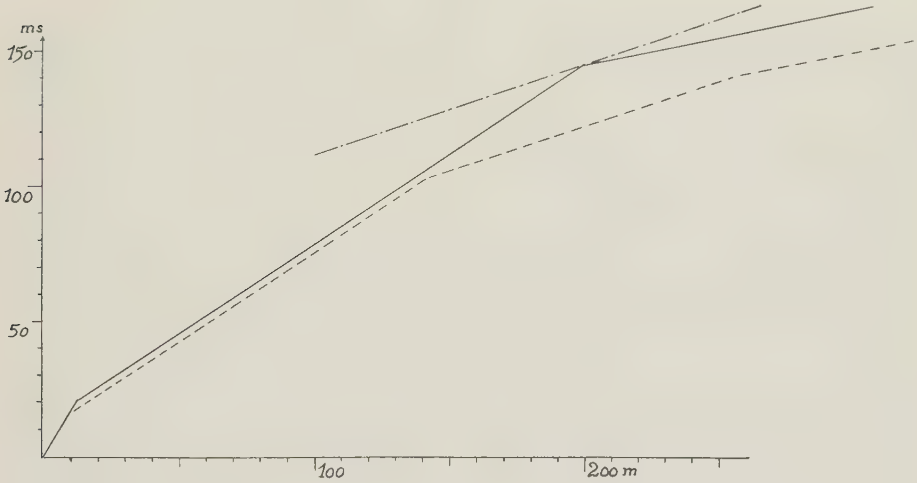

Fig. 3.

Un ensemble de considérations géologiques, sur lesquelles il n'y a pas à insister ici, semblait rendre cette seconde interprétation beaucoup plus vraisemblable que la première, et effectivement, un sondage mécanique a vérifié que le bed-rock n'atteignait pas la cote primitivement annoncée.

Ce petit exemple montre l'intérêt qu'il y a à disposer d'une méthode de

calcul assez rapide pour que l'interprétation d'un profil de sismique réfraction ne se fasse pas par un calcul unique, mais comporte toute une série de calculs, dans lesquels on fait varier tous les paramètres dont l'interprétation prête à discussion.

DISCUSSION

Mr. VON HELMS: In using the horizontal velocities determined from the time-curve for calculating the depth of the refracting layer the depths obtained will always be too great. To determine the depth with accuracy it is necessary to use the vertical or "inclined" velocity. How does the author overcome this difficulty?

(Interruption by the President—since Mr. Goguel is not present to answer we should not, perhaps, criticise his paper too much.)

Mr. GERMAIN-JONES: Vertical velocity information is not always available and, in these circumstances, we have found that it is quite satisfactory, from the point of view of the accuracy of refraction work, to apply to the depths calculated a factor learned from experience which will correct for the discrepancy.

Mr. VON HELMS: In unknown territory, we must calculate the dip and depth of each successive layer using reversed profiles. We must know the velocities and depths of all layers before calculating the deepest, and we must know the dip of all layers before the slide-rule can be used.

Mr. VAN WEELDEN: Mr. Goguel's first supposition is that the layers are horizontal.

Mr. HAGEDOORN: Gave a summary of the paper in English at the members' request, and undertook to reply to further questions.

Mr. VON HELMS: What velocities do you use?

Mr. HAGEDOORN: Velocities must be obtained by shooting reversed profiles. The depths obtained will be correct if the layers are not dipping very steeply.

Mr. GERMAIN-JONES: The computed depths will surely be an average depth between shot-point and the point of discontinuity on the time-curve.

Mr. HAGEDOORN: That will depend on the way of working. By projecting the t-x curve back, the intercept time is obtained, and the depth can be determined for any point. Provided the dip does not exceed about 10° the depths may be determined with sufficient accuracy. Allowance can be made for slight dips from the information obtained from the reversed shooting.

Mr. WYROBEK: The method is intended for the special problem of shallow layers where steep dips are rarely encountered. No doubt it could be extended to deeper layers.

REFLEXIONS MULTIPLES OBLIQUES *

PAR

H. RICHARD **

Abstract

After a short introduction, some examples of obliques multiple reflexions are treated and possible solutions given.

Introduction

L'existence de réflexions multiples constitue assez souvent un sérieux obstacle dans l'interprétation des coupes sismiques et il semblait voici quelque temps, que cet inconvénient se manifestait surtout dans les zones à tectonique calme, là où les horizons sont peu ou pas inclinés (cf. „Geophysics", janvier 1948). Mais, pendant ces dernières années, nous avons eu l'occasion d'enregistrer des réflexions très obliques probablement multiples dans des secteurs où les structures sont accusées et même faillées.

Après le rappel de quelques généralités il nous paraît donc intéressant de présenter des exemples particulièrement caractéristiques dont la reproduction nous a été autorisée par l'Azienda Generale Italiana Petroli, la Régie Autonome des Pétroles et la Société Nationale des Pétroles du Languedoc Méditerranéen.

En conclusion, nous donnons quelques remarques d'ordre pratique concernant les multiples.

Généralités

On appelle réflexions multiples les réflexions enregistrées en S lorsque le rayon sismique issu de P effectue plusieurs allers et retours entre deux miroirs réels M et M′ (figure 1a). Le miroir M″ image de M donnée par M′ est, en quelque sorte, une illusion d'optique.

Dans les cas les plus courants, M et M′ sont peu inclinés et approximativement parallèles. Cependant cette dernière condition peut ne pas être satisfaite (figure 1b) et les phénomènes se compliquent très rapidement lorsqu'il existe plus de deux miroirs réels engendrant des réflexions multiples. Nous n'insistons pas sur ces complications.

D'après l'expérience acquise et des considérations théoriques, les réflexions multiples donnent lieu aux remarques ci-après :

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* Presented at the Hanover Meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

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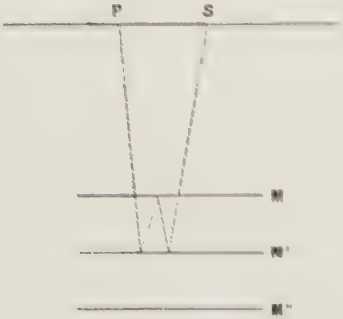
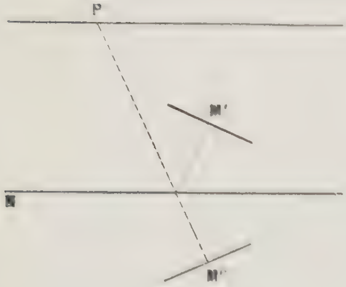
1° *Miroirs réels.* Les miroirs réels qui provoquent l'apparition des multiples sont constitués par des séries à grand pouvoir réflechissant : couches qui se distinguent du milieu sus ou sousjacent par une vitesse élevée ou une forte densité.

Exemple : une coulée de lave ; un banc calcaire.

2° *Réflexions au ras de la weathered zone* (WZ). Une couche à vitesse relativement grande au ras de la WZ engendre fréquemment des multiples.



(a) Miroirs parallèles



(b) Miroirs non parallèles
MM' : Miroirs réels ;
M'' : Miroir aberrant.

Fig. 1.

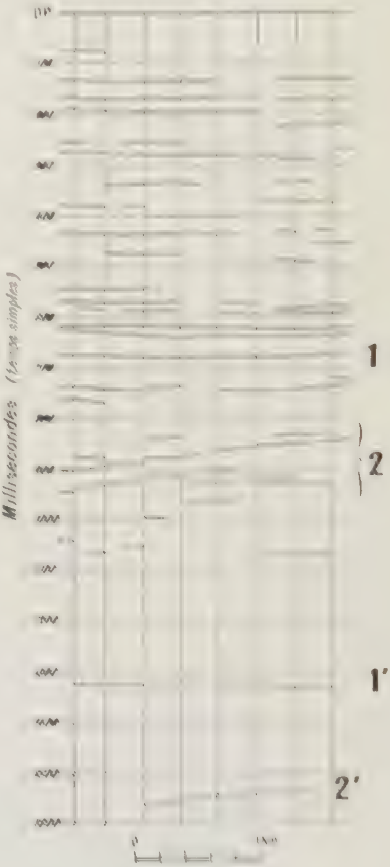


Fig. 2. Extrait d'une coupe sismique (Aquitaine).

Ce serait même le cas le plus fréquent, ou, du moins, le plus facile a diagnostiquer. L'onde émise par l'explosion se réfléchit sur une strate M, remonte jusqu'au bas de la WZ et accomplit un, deux, trois, etc. allers retours entre la WZ et M.

A titre d'exemple nous reproduisons sur la figure 2 un extrait de coupe sismique obtenue dans le Bassin d'Aquitaine (Sud de la France). Deux horizons virtuels apparaissent. Le 1′ vers 1330 millisecondes s'interprète comme l'image du ras de la WZ que donne la série 1 à fort pouvoir réfléchissant enregistrée vers 660-670 millisecondes.

L'horizon oblique 2′ vers 1540 millisecondes s'impute peut être à une multiple s'amorçant entre les strates inclinées comprises dans la série de miroirs 2.

3° *Conditions de surface.* Les réflexions multiples sont d'autant plus importantes que le rendement de la charge d'explosif est élevée dans les terrains de surface. L'emploi de plusieurs sismographes par trace ou de plusieurs explosions simultanées, améliore la qualité des sismogrammes, mais favorise l'apparition des multiples.

4° *Conditions du milieu élastique.* L'absorption et l'atténuation d'énergie par diffraction, diffusion, etc. doivent être faibles.

5° *Conditions tectoniques ou stratigraphiques.* Les miroirs continus et parallèles se révèlent plus favorables aux multiples que des miroirs petits ou discordants.

6° *Etude des vitesses* (méthode dite des △t par exemple). La détermination des vitesses par l'analyse des réflexions permet dans des circonstances favorables de reconnaitre si les miroirs sont réels ou virtuels (Nous en avons des exemples en Afrique du Nord).

7° *Identification des multiples sur une coupe ou sur des films.* La cote et le pendage des miroirs aberrants étant définis par la cote et le pendage des miroirs réels, les films ou la coupe montrent parfois sans trop d'ambiguité la relation entre les deux catégories de miroirs.

Par exemple, soit une couverture subhorizontale discordante sur un sédimentaire assez plissé. Les miroirs aberrants dus aux multiples dans le recouvrement et apparaissant dans le substratum, seront subhorizontaux tandis que les miroirs réels y seront plus pentés.

Nous signalons que l'on enregistre souvent des réflexions multiples entre la surface et le fond de l'Océan au cours des travaux sismiques en mer (la brusque variation de vitesse entre l'eau et l'air assure un fort pouvoir réfléchissant à la surface de l'eau).

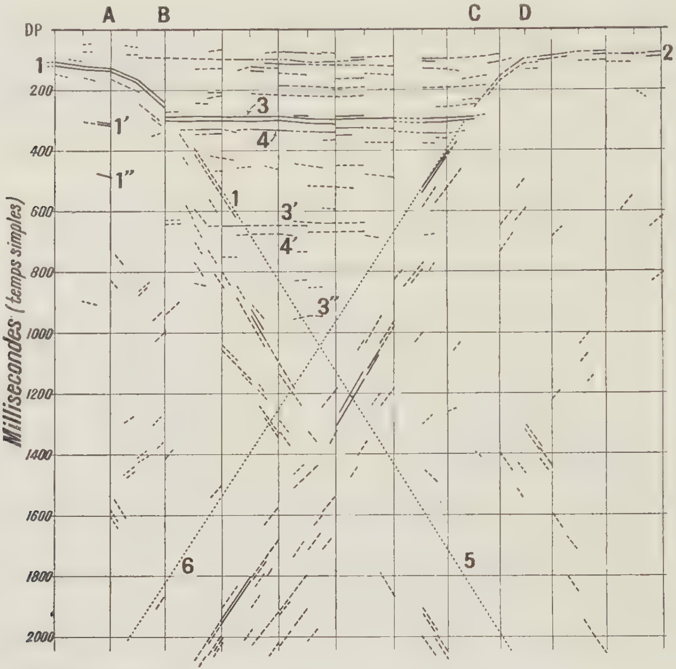
Enfin, le Dr. Poulter aurait observé que, dans le cas du tir en l'air, les multiples sont moins nombreuses et parfois même supprimées.

Réflexions multiples à fort gradient temps

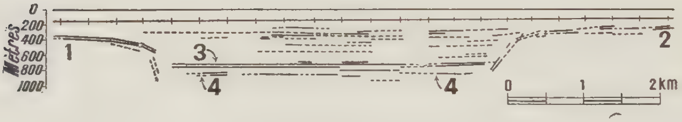
dans la Fosse Bradanique (Italie)

Nous reproduisons sur la figure 3 un élément de coupe sismique obtenue dans un pays faillé dont la prospection géologique et géophysique a fait l'objet d'une communication au récent Congrès Géologique International d'Alger (Esquisse structurale de la Fosse Bradanique, communication présentée par M. Jaboli de l'Azienda Generale Italiana Petroli et M. Roger de la Compagnie Générale de Géophysique).

Le profil, orienté perpendiculairement à la direction tectonique principale, recoupe un effondrement affectant un socle calcaire à faible profondeur : quelques centaines de mètres. Ce calcaire constitue un excellent repère géophysique qui se caractérise par : une forte densité, une résistivité élevée, une grande vitesse des ondes élastiques, un fort pouvoir réfléchissant. Sa tectonique a été étudié avec succès au cours d'une vaste reconnaissance par méthodes gravimétrique, tellurique/électrique, sismique réfraction et réflexion.



Coupe temps (Fosse Bradanique)



Coupe profondeur (sans réflexions multiples)
$V = 1800 + P$

Fig. 3.

L'accord entre les différents procédés s'avère parfait et il est établi que les horizons numérotés 1, 2, 4, dessinent sous un terrain lent argileux et sableux (V = 1.800 mètres/seconde, croissant lentement en fonction de la profondeur) le toit du milieu rapide : V = 5.300 mètres/seconde. Il est également démontré que, dans cette région, le sommet du calcaire et les séries immédiatement au-dessus: tuf puis argiles se comportent comme de très beaux miroir donnant souvent naissance à des réflexions multiples.

Dans l'exemple choisi, le substratum s'enfonce brutalement entre A et B, D et C. Entre B et C, les niveaux subhorizontaux 3-4 marquent le fond du graben.

Réflexions multiples subhorizontales. Les miroirs subhorizontaux enregistrés sous les niveaux 3-4 correspondent à des multiples. Les plus systématiques: série 3′-4′ (et 3″) sont des images de la WZ par rapport à 3 et 4. Il est très vraisemblable qu'il se produit en outre des allers-retours entre 3 et 4.

Réflexions multiples obliques. Prolongeons les horizons 1 et 2 au-delà de la cote 600 millisecondes par les fantômes 5 et 6 parallèles aux réflexions sous-jacentes: toutes les réflexions très obliques visibles sous 5 et 6 sont probablement des multiples.

Nous en verrions comme causes:

le grand pouvoir réfléchissant des séries au toit du calcaire;

l'épaisseur réduite de la couverture, et le faible pouvoir absorbant des terrains qui la constituent;

la propagation de l'énergie quasi-parallèle à la stratification suivant une partie de la trajectoire, point auquel nous revenons plus loin (comme il arrive fréquemment, la preuve qu'il s'agit de multiples n'est pas absolue, mais les présomptions sont très fortes);

parallélisme de l'ensemble des réflexions (on peut même avancer le paradoxe que le gradient temps du miroir réel se détermine ici grâce aux multiples!);

impossibilité géologique de les considérer comme des réflexions réelles;

durée: certaines s'enregistrent sur les films plus de 5 secondes après l'explosion, et avec des précautions spéciales: charges plus fortes, sensibilité plus grande de l'appareillage, cette durée pourrait être encore largement augmentée.

Il est curieux de constater que si nous percevons nettement les multiples nous se distinguons pas les réflexions réelles qui les provoquent. L'explication en est cependant bien simple.

Les fantômes 5 et 6 qui prolongent les horizons 1 et 2, devraient être jalonnés de miroirs réels, mais ceux-ci sont masqués par les multiples horizontales (séries 3′, 4′ notamment et 3″) et par le brouillage qui résulte de l'arrivée simultanée des nombreux trains d'ondes réfléchis sur le fond et sur les deux bords de l'étroit fossé.

Coupe profondeur. Les essais de construction de la coupe profondeur à partir de la coupe Temps originale ont abouti à une image excessivement confuse due à la multitude et à la dispersion des miroirs qu'apportent presque toutes les réflexions obliques assimilées à des réflexions réelles. On a donc opéré comme suit:

Figure 3: On conserve uniquement les séries 1, 2, 3, 4 et les niveaux réfléchissants contenus dans la couverture.

Les réflexions au-dessous de 1, 2, 3, 4 sont négligées.

La vitesse admise : V = 1.800 + P atteint 2.600 mètres/secondes au fond du graben.

Figure 4 : On se borne à construire les niveaux 1, 2, 3, 4, 5, 6 en envisageant six hypothèses théoriques. Pour faciliter les constructions, on suppose des vitesses uniformes. Cette simplification est licite car sur des épaisseurs aussi réduites, la vitesse varie peu.

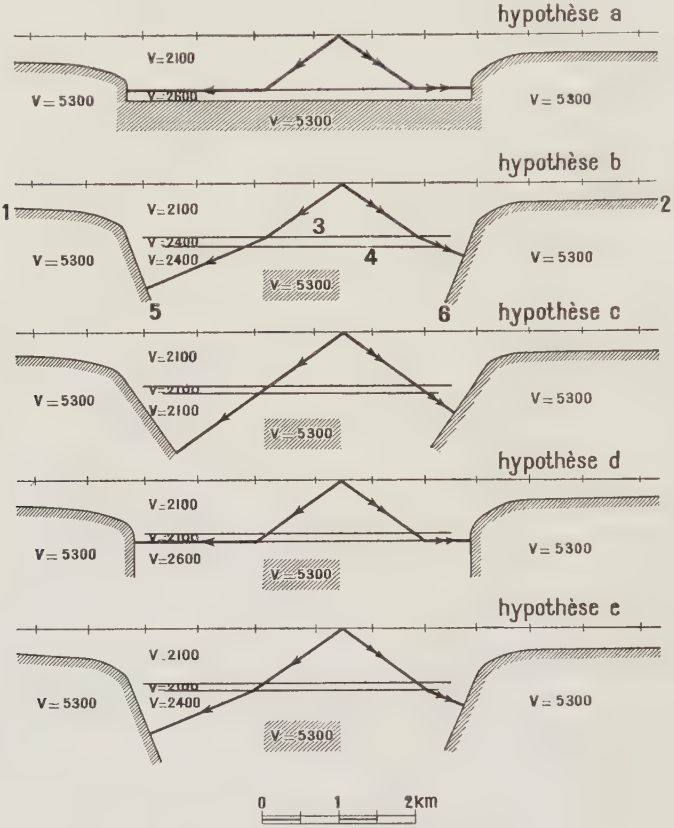


Fig. 4. Coupes profondeurs schématiques.

a) v = 2.100 mètres/seconde au-dessus du niveau 3
v = 2.600 mètres/seconde entre 3 et 4.

Dans ce cas extrême, les rayons avant d'être réfléchis par les horizons 5 ou 6 se réfractent totalement sur l'horizon 3. Les horizons 5 et 6 se placent verticalement.

b) V = 2.100 au-dessus du niveau 3
V = 2.400 entre 3 et 4
V = 2.400 au-dessous de 4.

Les rayons considérés se réfractent partiellement au passage de l'horizon 3.

c) V = 2.100 au-dessus du niveau 3
V entre 3 et 4
V au-dessous de 4.

Les rayons ne se réfractent pas.

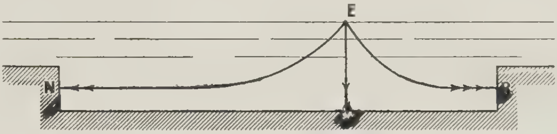
d) et e) reprennent a) et b) mais admettent que la réfraction se produit sur l'horizon 4.

Interprétation. Des hypothèses voisines de l'hypothèse a) paraissent les plus plausibles. Il faut en effet tenir compte de la présence du milieu rapide V = 5.300, immédiatement au-dessous de l'horizon 4. Dans ces conditions l'onde réfléchie sur le bord vertical du fossé a une trajectoire brisée (en pratique très courbée) qui, en profondeur, s'assimile à une horizontale.

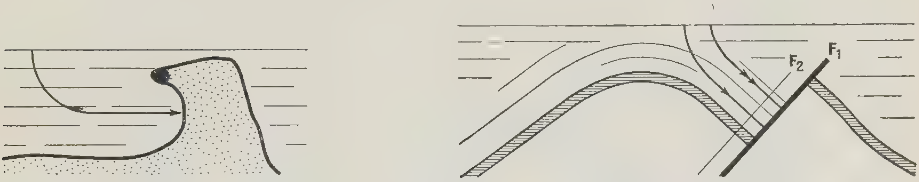
Comme l'indique le schéma de la figure 5a, on enregistre finalement au voisinage d'un point d'explosion E :

un rayon réfléchi sur le fond horizontal : EM. Ce rayon est vertical.

des rayons réfléchis sur les deux bordures verticales du fossé EN, ER. Ces rayons se rapprochent de l'horizontale.



(a) Cas du fossé étroit



(b) Cas du diapir

(c) Cas du pli faillé

Fig. 5.

Or, on constate que les réflexions sur la paroi subverticale sont aussi nettes que les réflexions sur le fond horizontal.

Les trajets EN et ER étant bien plus longs que le trajet EM, l'absorption d'énergie transportée sur ces trajets devrait être plus grande. Mais en fait, la propagation suivant EN et ER a lieu en majeure partie presque parallèlement à la stratification c'est-à-dire dans de bien meilleures conditions.

Un phénomène comparable se manifeste près de certains plis diapirs rencontrés dans le Bassin d'Aquitaine. Lorsque la stratification des terrains ceinturant le pointement n'est pas affectée par l'accident il est courant d'obtenir des réflexions franches sur la paroi du diapir (fig. 5b).

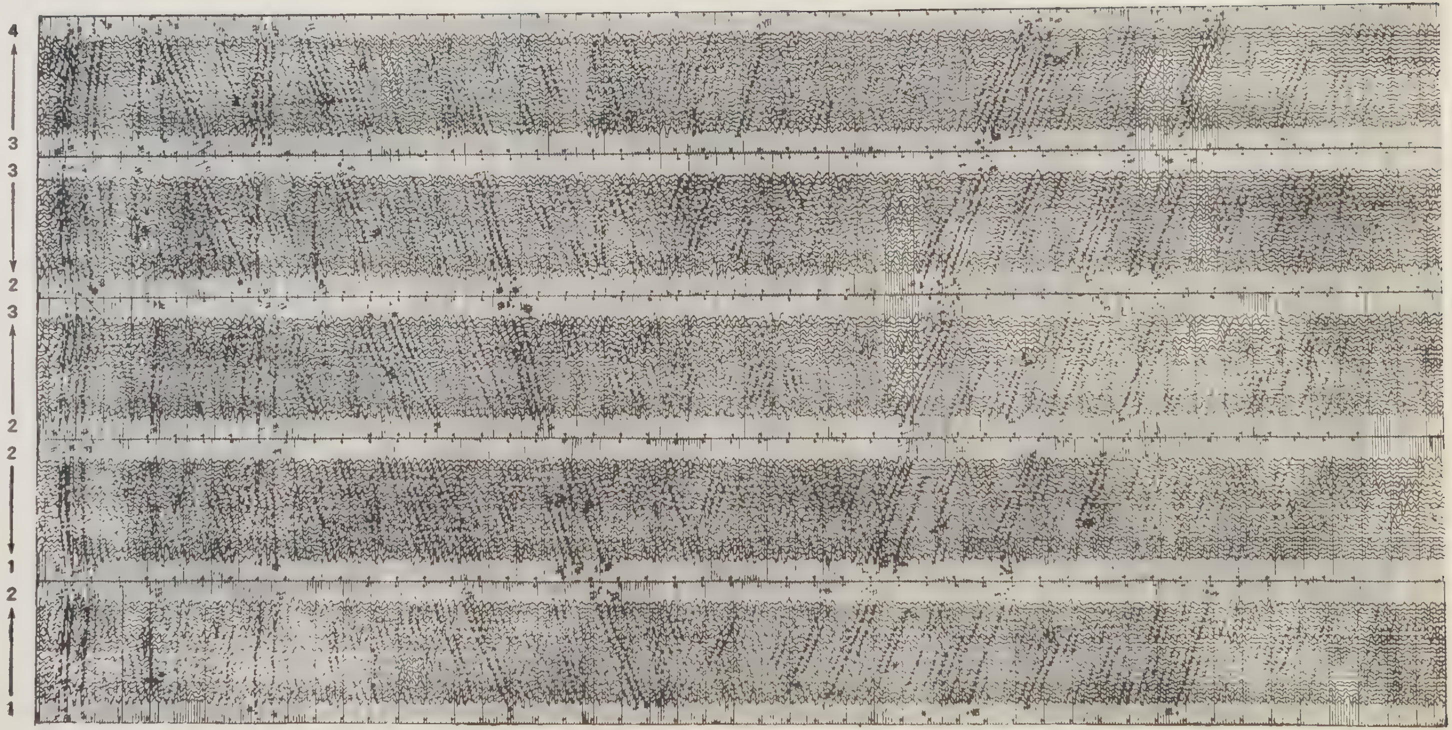


Fig. 6.

Il n'est évidemment pas nécessaire que la stratification soit horizontale et le miroir vertical.

Ainsi, dans le cas du pli faillé (fig. 5c) que nous avons également rencontré, l'énergie se propage très facilement parallèlement au flanc du pli et se réfléchit normalement au plan de faille F 1.

De ce qui précède, nous retenons que, dans la mesure où le plan de discontinuité: faille, diapir, flexure brutale, est perpendiculaire à la stratification, il est relativement facile d'obtenir de belles réflexions sur ce plan.

Pour expliquer en outre la formation des multiples constatées notamment dans les 5a et 5c, on peut supposer que l'accident majeur F 1 est accompagné d'une faille F 2 sensiblement parallèle, introduisant une discontinuité élastique suffisante pour que des multiples s'amorcent entre F 1 et F 2.

Présentation de films

(Fig. 6)

A l'appui de la coupe figurant sur le fig. 3, nous présentons 5 enregistrements jointifs réalisés avec le dispositif ci-après:

370 à 380 mètres entre points d'explosion.
24 traces entre points d'explosion.
15 mètres entre traces.
2 sismos par trace.

Pour alléger la planche, on a conservé seulement la partie de film enregistrée de 600 à 5.500 millisecondes après explosion et pour donner plus de relief aux multiples, des alignements s'appuyant seulement sur quelques traces ont été pointés, en plus de ceux retenus dans l'interprétation initiale.

Une sorte de „polarisation" parallèle aux horizons subhorizontaux et obliques apparaît ainsi très clairement.

Exemple emprunte au Languedoc

(Sud-Est de la France)

Tandis que le caractère virtuel de la plupart des réflexions obliques enregistrées dans la Fosse Bradanique semble peu discutable, il n'en est pas encore de même dans notre exemple emprunté au Languedoc.

Il existe entre ces deux secteurs plusieurs traits communs qui nous incitent cependant à suspecter la présence de multiples sur quelques coupes obtenues en Languedoc, et en particulier sur la coupe Temps reproduite sur la figure 7.

On rencontre sur ce profil des conditions lithologiques et tectoniques du même genre:

couverture de terrain lent: V = 1800 à 2600 mètres/secondes constituée ici par des séries marneuses tertiaires;

faible épaisseur de la couverture: quelques centaines de mètres;

substratum calcaire rapide : vitesse de l'ordre de 5.000 mètres/seconde ; formes accusées du toit du substratum.

La section de la figure 7 entre les points A et D offre une ressemblance saisissante avec la section A D de la figure 3. Il nous a même paru suggestif d'adopter pour les horizons intéressants une numérotation identique : 1—2—3—4—5—6.

Le profil, approximativement perpendiculaire aux directions tectoniques, recoupe ici une étroite dépression large de trois kilomètres dans laquelle plongent brutalement les horizons 1 et 2.

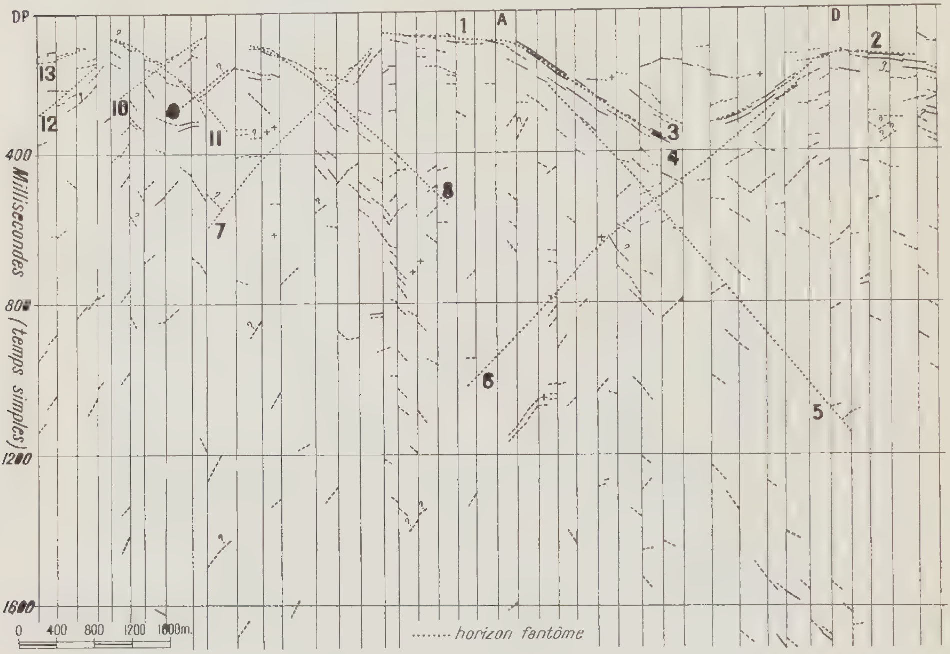


Fig. 7. Coupe temps (Languedoc).

Les niveaux 3 et 4 subhorizontaux sur la figure 3 se réduisent à quelques miroirs légèrement inclinés au milieu du fossé. Le fond de celui-ci n'apparait donc pas indiscutablement.

Réflexions Obliques

Par leur quantité, leur durée, leur parallèlisme et l'allure générale en X, les réflexions obliques rappellent celles de la Fosse Bradanique.

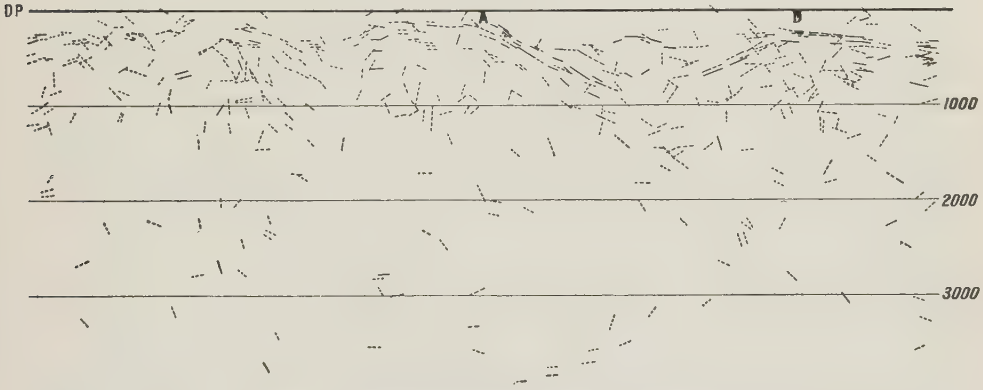
Les fantômes 5 et 6 raccordés tangentiellement aux horizons 1 et 2 se placent au-dessus de l'ensemble des réflexions obliques qui leur sont pratiquement parallèles sur la coupe Temps. A une petite translation verticale près, ils correspondent, si l'analogie avec la Fosse Bradanique est intégrale, à des miroirs réels d'où dérivent toutes les réflexions sous-jacentes qui dans cette hypothèse ne sont plus que des multiples.

Admettons que l'analogie s'étende à toute la coupe et traçons approximativement les horizons fantômes parallèles aux réflexions obliques sous-jacentes. Les horizons ainsi dessinés s'entrecroisent en X et paraissent délimiter des accidents étroits comme nous l'observons plus loin sur la coupe Profondeur schématique.

Coupe Profondeur brute
(Figure 8)

Nous reproduisons sur la figure 8 une coupe Profondeur brute déduite sans discussion de la figure 7.

1°) Il n'a pas été tenu compte du relief du substratum rapide. On a simplement admis que la vitesse croissait progressivement en fonction de la profondeur et ne variait pas dans le sens horizontal.



Essai de coupe interprétative très schématique

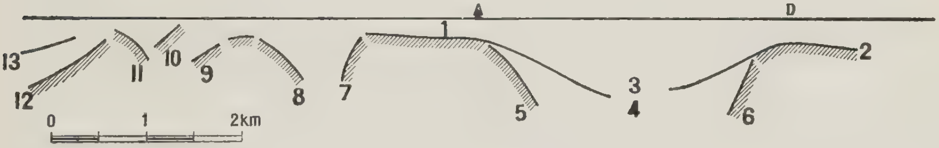


Fig. 8. Coupe profondeur brute (Languedoc) déduite de la Fig. 7.

2°) Toutes les réflexions portées sur les films ont été utilisées en supposant qu'aucune n'était multiple.

Dans ces conditions, on construit un nombre considérable de miroirs réels ou virtuels dont la position sur cette carte est sûrement aberrante. La dispersion des miroirs nous en paraît une preuve convaincante.

On en vient à supposer, du moins provisoirement, que, si dans leur ensemble, les réflexions se distribuent sur les enregistrements d'une manière ordonnée, cohérente, elles sont en relation dans l'espace, avec des formes structurales plutôt simples favorisant la propagation de l'énergie. En d'autres termes, après le précédent essai, nous suggérons de rechercher une vue plus simple, voire schématique, qui constituera le premier stade de l'interprétation.

Ce schéma sera perfectionné et complété plus tard, après discussions avec le géologue et compte tenu de nouvelles données ou de nouvelles hypothèses.

Essai de coupe interprétative très schématique

(bas de la Fig. 8)

Revenons à la figure 7 et retenons strictement les horizons numérotés de 1 à 13 qui dégagent les grandes lignes de la coupe Temps.

Hormis les fantômes 3-4 et 13 qui se placent dans la couverture et par analogie avec la Fosse Bradanique ces horizons sont alors censés représenter le sommet du calcaire.

Nous en déduisons, au bas de la figure 8, un essai de coupe Profondeur interprétative sur laquelle sont reportés tous les horizons.

En faisant varier les hypothèses sur les vitesses, on modifierait quelque peu cette esquisse, mais l'aspect général se conserverait: succession d'accidents étroits affectant le toit du calcaire. On peut à ce moment se demander dans quelle mesure l'étude du substratum relèverait d'une campagne réfraction ou électrique. Les accidents sont en effet peu profonds mais très rapprochés (quelques centaines de mètres).

Réflexions Multiples

En résumé, les réflexions multiples qui, d'après la similitude supposée avec la Fosse Bradanique, perturbent les enregistrements, prendraient naissance entre la surface du sol et le substratum. Elles créent sur la figure 7 l'illusion que l'on enregistre des réflexions à l'intérieur du calcaire.

Conclusions

De cet exposé, nous retiendrons que les réflexions multiples obliques paraissent surtout à craindre quand les conditions suivantes sont remplies:

substratum rapide peu profond aux formes accusées, mais relativement simples. (Dans l'hypothèse particulière d'un plan de discontinuité perpendiculaire aux strates, la propagation de l'énergie se fait plus facilement.)

couverture de terrain lent.

Lorsque le substratum s'enfonce à une assez grande profondeur, la vitesse dans les séries au bas de la couverture augmente. Le contraste de vitesse entre le socle et son recouvrement diminue et le risque de réflexions multiples dévrait également diminuer.

La présence effective des multiples obliques se démontre difficilement. Les calculs de vitesses à partir de l'analyse des temps, ne permettent pas comme dans le cas des multiples subhorizontales de les reconnaître. Les meilleurs critères seraient, semble-t-il :

enregistrement pendant un temps appréciable après l'explosion de nombreuses réflexions parallèles ou quasi-parallèles.

difficultés rencontrées pour aboutir à une coupe Profondeur cohérente.

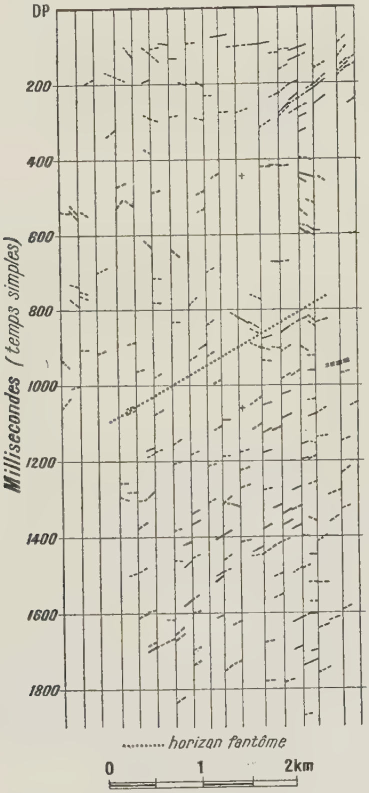


Fig. 9. Coupe temps (Languedoc).

possibilité sur la coupe Temps de remplacer les groupements de miroirs par quelques fantômes donnant les grandes lignes.

Le premier critère paraissant être le plus catégorique, un moyen de reconnaître des multiples consisterait par conséquent à :

tirer une assez forte charge d'explosif ;

faire un enregistrement très long, particulièrement soigné. Si la sensibilité de l'appareillage est suffisante, les multiples s'enregistrent pendant 10 secondes et plus après l'instant de l'explosion.

L'expérience serait par exemple à pratiquer sur la coupe de la figure 9 enregistrée en Languedoc près du profil analysé dans les pages précédentes.

Interprétation

Il convient de remplacer l'ensemble des multiples par des éléments de fantôme satisfaisant sur la coupe Temps à trois conditions:

être parallèle aux multiples.

être au-dessus des multiples.

s'appuyer si possible sur quelques réflexions présumées réelles.

Cette opération implique un certain risque comme le souligne la figure 9: L'horizon tracé au-dessus de l'important groupement de miroirs est peut-être placé beaucoup trop bas.

Notons à la décharge des multiples, que lorsque les réflexions réelles sont masquées par des arrivées d'énergie parasites, les multiples permettent parfois de mesurer leur gradient temps, de déceler des accidents, etc....

Concluons enfin que le sismicien a toujours le devoir d'attirer l'attention du géologue sur le caractère aléatoire d'une coupe Profondeur construite d'une façon trop mécanique. La sismique exige souvent autant d'esprit critique que les autres procédés: gravimétrique, magnétique, électrique.

Discussion

Mr Goguel: Je voudrais savoir quelles sont les couches géologiques?

Mr Richard: Les couches géologiques, dans les deux problèmes, sont des couches constituées par des roches Secondaires caractérisées par des vitesses très élevées de l'ordre de 5000 m, la couverture étant constituée par des terrains récents, sur un Tertiaire dont la vitesse est de l'ordre de 2000 à 3500 m. Autrement dit, le contraste des vitesses entre la couverture et l'horizon qui donne des multiples est de l'ordre de 1 à 2. Il est constitué: du substratum calcaire, la couverture étant marneuse, argileuse ou sableuse.

Mr Goguel: Alors ce sont des roches calcaires?

Mr Richard: Oui.

Mr Goguel: Tertiaire?

Mr Richard: Secondaires et calcaires — au-dessous nous ne savons rien.

A une question de Mr Sumi, Mr Richard répond: Ici, je ne parle pas en géologue, faisant des hypothèses sur un pays assez compliqué. En somme, le problème traité est celui des couches intermédiaires entre la couverture et le substratum calcaire, la vitesse de ce dernier étant très grande.

Mr Goguel: Est-ce que, en ce qui concerne l'exemple du Languedoc, on ne pourrait pas parler plutôt de réfractions que de réflexions multiples.

Imaginons qu'il y ait une faille verticale qui limite le bassin avec des couches horizontales.

On voit donc, au point d'explosion, qu'il y a plusieurs rayons qui peuvent arriver, normalement, au miroir avec des trajets qui les font descendre plus ou moins bas. Je me demande si les miroirs plans que l'on observe ne représentent pas des réflexions sur ce rebord par des rayons refractés suivant des trajets différents; auquel cas c'est le rayon supérieur passant par des niveaux stratigraphiquement les plus récent qui donnera le miroir le plus lointain et le plus profond.

Il me semble que l'apparence des coupes que nous avons vue mérite au moins d'être examinée dans cette hypothèse.

Mr Richard : Je crois que nous avons déjà envisagé cela; en fait, dès que nous allons plus profond, nous entrons dans un milieu beaucoup plus rapide.

Avec un temps de parcours donné j'ai une propagation beaucoup plus grande et mon rayon réfléchi devrait se placer beaucoup plus loin. J'arrive à une hypothèse absurde.

J'ai été obligé, dans l'exemple que je tire de la fosse Bradanique, d'admettre une réflexion.

Si j'admets que la réfraction se produit à une plus grande profondeur et sur terrain rapide, j'aurai une trajectoire beaucoup plus longue. J'aurai donc un champ de miroirs entre deux accidents.

Remarques sur la coupe No. 8 Languedoc.

En effet, la coupe est interprétée sans tenir compte, chose impossible à faire à priori, du chevauchement qu'a révélé le sondage. Dans cette coupe on retrouve l'horizon 7 sous l'horizon 1 qui représente des calcaires du Jurassique moyen. On a retrouvé, sous l'horizon 1, des horizons éocènes qui sont le remplissage de ce bassin. Il y a donc manifestement un chevauchement. Les miroirs ne sont pas très clairs, mais il y a là une possibilité d'interprétation qui peut-être s'accorderait assez bien avec la figure de droite, où on voit la faille non pas verticale mais inclinée.

Mr Kunetz : Je voudrais demander à M. Richard si la réflexion est nécessairement d'une qualité nettement supérieure aux multiples qu'elle donne.

Mr Richard : Les multiples sont très belles et plus propres, parce que dépouillées d'un certain nombre de domes parasites.

E.A.E.G. ABSTRACT SERVICE

At the Inaugural Meeting of the E.A.E.G. held on 14th December, 1951, it was proposed that an abstract service should be organised as an aid to members in the task of keeping in touch with geophysical activity and developments throughout the world. A committee of three (B. Baars, A. A. Fitch, D. T. Germain-Jones) was formed to examine the proposition and, as a result, the first set of abstracts, covering publications during 1951, was distributed in May, 1952. Since that time a further set has been issued. Now that we have launched our own journal, it is intended to devote a section of it to the Abstract Service; and, to make the latter as complete as possible in its new form, the abstracts already distributed on the loose sheets are being reprinted.

This Abstract Service is made possible through the kind co-operation of the Anglo-Iranian Oil Company. The geophysical department of that company organised an abstract service for its own staff some years ago, and it has now extended the benefits of the service to members of the E.A.E.G. We take this opportunity of expressing our deep appreciation of this generous and valuable help.

The abstracts are divided into the following categories:

EXPLORATION — GENERAL
SEISMIC — GENERAL
— INSTRUMENTAL
— FIELD TECHNIQUE
— INTERPRETATION
— THEORY & RESEARCH
GRAVITY — Sub-divided as above.
MAGNETIC — Sub-divided as above
ELECTRICAL
GEOCHEMICAL
OTHER METHODS

Thus there are seven main sections, with the three more important ones (from the oil industry's point of view) each subdivided into five subsidiary sections. Where there may be doubt regarding the correct category to which an abstract should be assigned, confusion will be avoided as far as possible by a system of cross references.

Telluric current and radio wave methods will be classed as 'Electrical'. Well-logging techniques will be included only when they have a direct bearing on the geophysical field work, or are used with the object of facilitating the interpretation of such work.

When it is available, use has been made of the abstract published by the author: in other cases, the abstract has usually been prepared by the geophysical staff of the Anglo-Iranian Oil Company, or by the various country representatives within the E.A.E.G.

D. T. G.-J.
B. B.
A. A. F.

ABSTRACTS

EXPLORATION — GENERAL

1. *Post-Graduate Studentships.*

Editorial, Petroleum Times, Vol. 55, No. 1396, p. 78, Feb. 9, 1951.

Since the end of the war the Shell Petroleum Company has continued its policy of helping students of geology and geophysics through British universities, and since 1945 150 students have been given assistance. Today there is greater need for post-graduate assistance, and a number of grants, at £375 a year, are being added in 1951 to the several already awarded. Particular encouragement is being given to the spreading of geophysical studentships over a greater number of universities.

2. *Some Requirements for Future Progress in Geophysical Prospecting.*

H. M. Thralls, World Petroleum, Vol. 22, No. 3, March, 1951.

A discussion, mainly from the point of view of a Geophysical Contracting Co., of the lines on which progress must be made in order to keep abreast of increasing difficulty of locating oil structures. The necessity of closer co-operation between the Geophysicist and the Geologist is emphasized, and illustrated by the way in which the new technique was developed by S.S.C. for locating oil-filled sand-lenses in beds of shale.

3. *Airborne Aids to Oil Development in Canada.*

J. H. Cornell, World Petroleum, Vol. 22, No. 4, pp. 56-57, April, 1951.

The article describes briefly the part played by aircraft in the search for oil. It is shown how a great saving of time, labour and expense is effected.

Helicopters are ideal for transporting seismic crews in rough country but, as yet, their loading capacity prohibits the carrying of drilling equipment.

There are descriptions of the photographic survey of Canada, being carried out by The Photographic Survey Corp. Ltd., and of the application of the airborne magnetometer.

4. *Avenues for Progress in Geology and Geophysics.*

P. Weaver, World Oil, Vol. 132, No. 5, pp. 102-106, April, 1951.

Although there remains much room for improvements in technical skills to find oil and gas structures, the author presents a thought-provoking discussion of five things the geologist and geophysicist can do with data now available. In this "mopping up" operation, the accent is on the smaller and more difficult-to-find structures, and the author makes a plea for careful treatment of all data. This paper is based upon a talk given by the author at the Los Angeles meeting of the A.A.P.G. in November, 1950.

5. *Regional Stratigraphic Analysis as a Guide to Geophysical Exploration.*

W. C. Krumbein, World Oil, Vol. 132, No. 5, pp. 99-100, April, 1951.

While it has not been used to its full extent, there is another practical tool available for a logical approach to finding new petroleum structures. Although stratigraphic analysis is not entirely new, many of the methods of presenting data, mapping, etc., have provided an important basis for planning programmes of geological and geophysical exploration when used in conjunction with structural data, paleogeology and other kinds of regional information. The author presents a resumé of the application of regional stratigraphic analysis as a guide to geophysical exploration in areas of highest stratigraphic preference.

6. *Accuracy Factors in Geophysical Prospecting.*
N. J. Smith, World Oil, Vol. 132, No. 5, pp. 84-88, April, 1951.

Factors which affect the results obtained by the three primary methods of geophysical exploration are discussed. This is a qualitative analysis of these factors and of the accuracies which can be expected with relation to each of the three methods, and a brief explanation of how and why the factors listed influence interpretations. This may be described as an evaluation of the three methods of geophysical prospecting: Gravity, Magnetics and Seismic.

7. *Better Geophysical Interpretations.*
R. F. Beers, World Oil, Vol. 132, No. 5, pp. 80-82, April, 1951.

In these days of increasingly intense search for oil pools, much is heard about the need for a new geophysical tool. What this new tool may be we do not yet know. Right now there is a job to do with the tools we have got. Something can be done, probably in the way of 'gadgeteering' refinement, but we can do even more on the frontier of plain ordinary human action and co-operation. The purpose of this article is to explore ways in which the client can co-operate with geophysical contracting companies to improve the value of geophysical surveys all along the line.

8. *Exploration Geophysics—Yesterday—Today—Tomorrow.*
W. M. Rust, Jr., World Oil, Vol. 132, No. 5, pp. 76-78, April, 1951.

In a short span of 30 years, geophysics has become indispensable. The author goes into the background of this earth science and shows how it has progressed. What can we expect in the immediate future from geophysics? No miraculous invention or discovery will solve all problems, but a more intelligent utilization of present tools, supplemented by cost-saving aids, will do much in finding new sources of oil.

9. *New Developments in Geophysical Prospecting.*
L. J. Neuman, World Oil, Vol. 132, No. 5, pp. 90-96, April, 1951.

This article briefly summarizes major developments which have taken place in the geophysical industry during the past year. No effort is made to discuss detail, but the highlights of the major developments that had a broad effect are considered. Topics mentioned include equipment and technique in reflection seismograph, gravity meter, and magnetic surveys.

10. *Survey Tool Aids Bahrein Is. Oil Search.*
The Oil Forum, Vol. 5, No. 4, pp. 130-131, April, 1951.

The Bahrein Petroleum Co. Ltd., established a Decca navigator network for its offshore survey work in the Bahrein Island group of the Persian Gulf about two years ago, and the system has proven itself worthy of consideration by other oil companies engaged in similar work.

Underlying principle of the Decca system consists in the generation by radio transmitting stations of a set of stable standing-wave patterns. These patterns form co-ordinates in terms of which a radio receiver carried by the user provides continuous identifications of its position. The geographical positions of the ground stations being known, the data given by the receiver are directly convertible into co-ordinates of latitude and longitude. The conversion is effected by means of a map or chart over-printed with the 'red and green' system co-ordinates.

11. *Geophysical Crews Off Qatar Coast.*
The Oil Forum, Vol. 5, No. 4, p. 138, April, 1951.
At present three geophysical crews are actively engaged in this Persian Gulf survey off Qatar. A gravity meter crew is working off the east coast of Qatar, using Superior's 450 ton motor vessel "Jennings", as a mother ship, and dhows for close in work. A seismograph crew based on Bahrein Is. west of Qatar is employing two 104 ft. Navy crash boats, also supported by dhows. The work of these crews is supplemented by a conventional survey team. Tentative plans call for sufficient survey to have been completed to enable selection of a drill site by, or before, October, 1953.

12. *World Exploration Survey.*
The Oil Forum, Vol. 5, No. 4, pp. 136-137, April, 1951.
A brief survey of the position of oil exploration in various parts of the world.

SEISMIC — GENERAL

13. *Exploring for Pennsylvanian Reef Reserves in W. Texas.*
S. Harris, World Petroleum, Vol. 22, No. 3, March, 1951.
A general description of the seismic technique and difficulties encountered, in the search for reef structures. Suggestions are made on methods of examining the data in order to ensure the greatest possible amount of information. The article is illustrated.

14. *Seismic Refraction Experiments in the North Atlantic.*
T. F. Gaskell & J. C. Swallow, Nature, Vol. 167, No. 4253, pp. 723-4, May, 5, 1951.
This communication indicates briefly the results obtained of refraction observations in the North Atlantic during the Summer of 1950. The experimental method, using depth charges as sources of sound waves and sonoradio buoys as detectors, is similar to that used in the previous year by Hill and Swallow. Lines up to 17 miles long were shot, giving 10-15 first arrival observations. The results from the five stations occupied are summarised. The probable error of individual determinations of velocities is less than 5 %.

15. *Discussion of Seismic Reflection Quality Map of the U.S.*
P. L. Lyons, Geophysics, Vol. 16, No. 3, pp. 506-510, July, 1951.
A reflection quality map of the U.S. has been prepared by a sub-committee of the programme and arrangements committee of the S.E.G. The map designates as good, fair, poor or "N.G." all sedimentary areas where sufficient knowledge from conventional seismic operations is available. The map may be used in the planning of geophysical operations. Reflection quality is a function of many geological factors, and an attempt is made to correlate, very loosely, reflection quality with geology, or geological history.

SEISMIC — INSTRUMENTAL

16. *Miniature Seismograph Features Performance Plus Portability.*
H. J. Girard, Oil Gas J., Vol. 50, No. 3, pp. 96-97, 128-129, 1951.
An illustrated account of the use of Southwestern Industrial Electronic Co.'s P-11 equipment by various geophysical parties, chiefly in Canada.

SEISMIC — FIELD TECHNIQUE

17. *Seismic Oil Prospecting with an Air-Cleaned Drill.*

World Petroleum, Vol. 22, No. 3, March, 1951.

A description of technique of drilling with compressed air. The results are given of experiences with this type of drill in dry regions such as W. Texas, and extremely cold areas as are encountered in Canada. Drilling with air has considerable advantages over the normal water drilling in these areas.

18. *Air Drilling in Seismic Surveys.*

W. E. Burke, World Petroleum, Vol. 22, No. 9, p. 38, August, 1951.

While the method has not yet proved practical in all areas, it has been successful in medium and hard formations.

In areas where sand and gravel predominate, water drilling often proved more efficient; that is, where water was readily accessible, for the use of heavy drilling muds and other mediums were available to seal off the loose sand and gravel. The use of air in this type of drilling was handicapped in that there was no efficient way to keep the loose formation from falling back into the hole.

The air drilling method proves economical in that it does not use water trucks. It proves cleaner in that no mud pits are needed. It has proved faster than water drilling in some areas and also to be rather easier on the rock bit cones and bearings.

19. *Continued Research Improves New Exploration Tool.*

A. J. Baxter, World Petr., Vol. 22, No. 7, pp. 40-42, July, 1951.

The development of the Poulter method of seismic exploration is described. It consists of detonating a pattern of small explosive charges above the surface of the ground. Obviously there are limitations to the use of the method in densely populated areas but where its use is possible it has been found to possess many advantages over the conventional methods. The absence of drill-holes saves the time and expense of drilling rigs and cumbersome tankers.

Dr. Poulter submitted his inventions to the Institute of Inventive Research in San Antonio in 1947.

20. *Patents.*

Abstracts in Geophysics, Vol. 16, No. 3, p. 520, July, 1951:

U.S. 2, 545, 380. 13 March, 1951. Seismic exploration method using elevated charges (Poulter Method).

Abstracts in Geophysics, Vol. 16, No. 4, p. 702, October, 1951:

U.S. 2, 555, 806. 5 June, 1951. Shot firing method that produces a cylindrical wave front.

U.S. 2, 556, 299. 12 June, 1951. Method of shot firing that produces directional seismic waves.

U.S. 2, 557, 714. 19 June, 1951. A recording arrangement intended to facilitate the identification of reflections.

Abstracts in Geophysics, Vol. 17, No. 1, p. 139, January, 1952:

U.S. 2, 569, 411. 25 September, 1951. A special method of reflection shooting in a well.

SEISMIC — INTERPRETATION

21. *An Approximate Correction Method for Refraction in Reflection Seismic Prospecting.*

T. Krey, Geophysics, Vol. 16, No. 3, pp. 468-485, July, 1951.

Equations are derived and discussed to compute approximate corrections which must be applied to the results obtained by the classical method of computing and constructing data in reflection seismic prospecting, (this includes the method of construction of seismic image point and the method of seismic prospecting using zero-spread time) to correct for refraction. In addition, the influence of refraction on the determination of average velocity as obtained by applying the time-square distance-square curve (Time-Delta-Time Velocity) is analysed.

22. *Weathering and Other Surface Shooting Problems.*

N. Clayton, World Oil, Vol. 132, No. 4, pp. 57-58, March, 1951.

Although the Poulter or surface shooting method of seismic exploration is comparatively new it is becoming widely accepted in the industry, and this article discusses some of the problems peculiar to this type of geophysical exploration. Suggestions are made for handling the weathering problem, the most difficult with which the interpreter is confronted in a programme of this type.

23. *Seismic Refraction with Variable Velocity.*

J. M. Goguel, Geophysics, Vol. 16, No. 1, pp. 81-101, January, 1951.

The results of an investigation of methods of interpreting and calculating the propagation of seismic waves with variable velocity in contrast to an assumed constant velocity is presented. One of the major purposes of this study is to establish a calculation method for use in seismic refraction work that can be applied to existing types of alluvia and similar geologic formations. In addition to presenting the necessary tables and graphs used for such computations, two examples from actual field experience are shown.

SEISMIC — THEORY & RESEARCH

24. *An Electromechanical Source of Elastic Waves in the Ground.*

F. F. Evison, Proc. Phys. Soc., Vol. 64, Pt. 4, No. 376B, pp. 311-322, April 1, 1951.

In order to extend the study and use of the elastic properties of geological bodies to include effects involving the amplitude and frequency of elastic radiation, a new source of energy is needed.

A large moving coil transducer is described which, when attached rigidly to the rock, radiates sinusoidal vibrations of controllable amplitude, frequency and duration. The operation of the vibrator is analyzed in detail by the method of electromechanical analogy.

For experiments in a chalk mine, energy at each of the frequencies 300, 600 to 1,000 c/s. was radiated in the form of a square enveloped pulse, of 20 m/sec. duration. Vibrations were detected in the rock by means of a piezoelectric microphone, amplifiers and an oscillograph, with an overall magnification of about 10^9. Oscillograms show the complex disturbances produced by the arrival of direct and reflected energy, at distances out to the limit of 450 ft. Measurements of amplitude at 130 ft. are used to examine the mechanism of the transfer of energy from the vibrator to the rock.

The power radiated was about 0.05 watts at 60 c/s., of which about one sixth was in the compressional mode and five sixths in the shear mode; but this power may readily be increased.

25. *Normal Mode Propagation in Three Layered Liquid Half-Space by Ray Theory.*

C. B. Officer, Jr., Geophysics, Vol. 16, No. 2, pp. 207-212, April, 1951.

The fundamental integral for normal mode propagation in a three liquid layered half-space is derived by multiple reflections and the physical significance of the characteristic equation is discussed.

26. *Ground Roll Coupling to Atmospheric Compressional Waves.*
F. Press & M. Ewing, Geophysics, Vol. 16, No. 3, pp. 416-430, July 1951.

A theoretical treatment of ground roll originating from air shots and hole shots is given. It is shown that coupling of ground roll to compressional waves in the atmosphere exists for both air shots and hole shots. Experimental data obtained in the field are in excellent agreement with the theoretical results; namely, that the effective coupling exists for surface waves whose phase velocity is equal to the speed of sound in air.

In regions where Rayleigh wave velocities vary with period due to layering in such a way that they are less than the speed of sound in air for short periods and exceed this value for longer periods, this coupling gives rise to a unique surface wave pattern on seismic records.

It is shown that body wave and surface wave character is almost independent of charge elevation in the range from 0 (on the ground) to 30 ft.

In a reciprocal manner ground roll from hole shots was recorded with air microphones as predicted by the theory.

27. *The Form & Laws of Propagation of Seismic Wavelets.*
N. Ricker, Proc. Third World Petr. Cong., 1951, Section 1, p. 514-536.

An attack has been made on the problem of the form of the seismic disturbance which proceeds outward from the explosion of a charge of dynamite, and the laws of propagation of this disturbance. A mathematical theory was developed about ten years ago, and a small amount of experimental work carried out at that time encouraged further efforts. Recently an extensive series of experimental researches has been carried out in a sensibly homogenious shale section, and as a result of these studies a rather clear understanding of the form and nature of the primary seismic disturbance, and its laws of propagation, has been obtained for shale.

As a result of these researches it may be concluded that, in shale, agreement of experiment with the wavelet theory has been good. These checks are relative to: (1) the form of the disturbance; (2) the law of broadening; (3) the law of amplitude delay with travel time for the earth-particle velocity; (4) the spectrum of the disturbance.

In addition to the above the effect of size of charge on the amplitude has been checked in special experiments and found to be close to the 5/6 power law.

28. *Laboratory Studies of Transient Elastic Waves.*
S. Kaufman & L. Roever, Proc. Third World Petr. Cong., 1951, Section 1, pp. 537-545.

An experimental procedure for model studies of the propagation of transient elastic waves is described, and some of the preliminary results are presented. These indicate that this method of approach to the complicated seismic problem may be a fruitful one. Although some workers, on the basis of earthquake and atomic bomb observations, have questioned the results of classical theory, evidence concerning the character of the surface-propagated Rayleigh waves has been obtained which is in agreement with theory.

It is admitted by the authors that the work done so far has been exploratory, but it is claimed that it has been shown that model experiments of this kind are quite feasible and that results of practical interest can be obtained. The classical theory seems to be adequate for the simple homogeneous case. It is planned to continue this work with other media, both homogeneous and layered.

29. *A Study of the Influence of Background Noise on Reflection Picking.*
K. Dyk & J. D. Eisler, Geophysics, Vol. 16, No. 3, pp. 450-455, July, 1951.

To evaluate the ability of interpretational personnel to pick reflected energy in presence of variable amount of noise, recordings were made using random ground unrest and superimposing thereupon a controllable amount of synthetic reflection energy. The description of apparatus used and the results of picking of such records are given.

GRAVITY — GENERAL

30. *Deviation of the Vertical.*

A. R. Robins, Empire Survey Review, Vol. 11, No. 79, pp. 28-36, 1951.

The procedure for the precise determination of the deviation of the vertical, sources of error, and the necessary equipment are described.

31. *World-Wide Gravity Programme of the Mapping and Charting Research Laboratory of the Ohio State University.*

W. Heiskanen, Geophysics, Vol. 16, No. 4, pp. 697-700, October, 1951.

Gravity anomalies are an important tool in the hands of the exploration geophysicist. But they also have a very great geodetic significance. They enable us to determine the shape of the earth—the only method which, at least now, can do it. The gravity anomaly maps of the earth, which present, in broad lines, the gravity field of the world, enable us to compute the undulations of the geoid. We can also by means of these anomaly maps compute the absolute deflections of the vertical at any point, in the vicinity of which local gravity survey exists—at least about 100 stations inside the circle of 220 km. radius. By means of these absolute deflections of the vertical, we can convert the astronomical positions to the geodetic ones.

We have in the Mapping and Charting Research Laboratory in Columbus planned a world wide gravity programme by the aid of which we can obtain the following aims:

1. To determine a general world geodetic system and to convert the geodetic systems, (North American, European, Russian etc.) to this system.
2. To be able to compute, on the world geodetic system, the geographical co-ordinates of any important points in the world where astronomical observations exist or which is plotted on a local map with a reliable grid.
3. To be able to compute the distances and directions between any required points in the world.
4. To control the maps on scale 1 : 100,000 and on smaller scales.
5. To study the size and shape of the earth's ellipsoid and geoid.

About 3,000 new gravity stations, evenly distributed, and many local gravity surveys and, of course, an enormous amount of analysing work are needed. Many leading scientists and some universities have already promised a close co-operation. We hope to get much valuable help from the side of the prospecting geophysicist.

GRAVITY — INTERPRETATION

32. *Combined Analysis of Gravity and Magnetic Anomalies.*

G. D. Garland, Geophysics, Vol. 16, No. 1, pp. 51-62, January, 1951.

The relationships between gravity and magnetic anomalies is investigated. It is shown that the ratio of the anomalous susceptibility to the anomalous density of an unknown body may be determined from gravimeter and vertical magnetometer observations, independent of assumptions as to the depth or form of the body. The use of this ratio in identifying the rock material of the body is discussed, and illustrated by applying the method to a well-known case.

33. *The Second Derivative Method of Gravity Interpretation.*

T. A. Elkins, Geophysics, Vol. 16, No. 1, pp. 29-50, January, 1951.

The second derivative method of interpreting gravity data, although its use is justifiably only on data of high accuracy, offers a simple routine method of locating some types of geologic anomalies of importance in oil and mineral reconnaissance. The theoretical formula by which it is possible to compute the second (vertical) derivation of any harmonic function from its values in a horizontal plane is derived for both the two-dimensional and the three-dimensional cases. The graphical method of computing the second derivative is discussed, especially as to the sources of error. A numerical coefficient equivalent of the graphical method is also presented.

Formulae and graphs for the second derivative of the gravity effect of such geometrically simple shapes as the sphere, the infinite horizontal cylinder, the semi-infinite horizontal plane, and the vertical fault, are presented with discussions of their value in the interpretation of practical data. Finally, the gravity and second derivative maps of portions of some important oil provinces are presented and compared to show the higher resolving power of the second derivative.

34. *Graphic Adjustment by Least Squares.*
A. E. Smith, Geophysics, Vol. 16, No. 2, pp. 222-227, April, 1951.

The gravity meter in use today measures the differences in the acceleration of gravity between stations. When three or more gravity stations are interconnected by measured differences to form closed gravity station networks, values for the acceleration of gravity at all stations must be derived in such a manner that around all closed circuits the algebraic sum of the adjusted gravity differences is zero. Since the errors involved are assumed to be random, a solution can be obtained by the method of 'Least Squares'. However, for large networks, the usual least squares solution is so time-consuming that it is frequently omitted in cases where its application would be desirable. It is the purpose of this paper to describe the practical application of a more speedy method.

GRAVITY — THEORY & RESEARCH

35. *The Geodetic Uses of Gravity Measurements and Their Appropriate Reduction.*
J. de Graaff-Hunter, F.R.S., Proc. Roy. Soc. No. 1084, Vol. 206, pp. 1-17, 22 March, 1951.

In part 1 are stated the needs of geodesy which must be met to allow results to be expressed in one unique reference system. At present the great surveys are in disconnected systems and are partially geoidal. Part 2 recalls a Theorum of Stokes, relating geoid with spheroid. Thence are deduced expressions for the deviations of the vertical and the curvature of the geoid. All these are in the form of integrals of the gravity anomalies over the earth. Part 3: this ideal earth is a body bounded by a level surface, and to bring the actual earth into its scope, protuberances of the topography above the co-geoid—a surface differing slightly from the geoid—must be annulled. Part 4: the relation between gravity at different levels is found in terms of the local mean geoidal curvature, instead of the customary mean of the whole earth. In part 5 a practical observational method of finding this curvature is proposed, depending on reciprocal vertical angles observed at pairs of points. Atmospheric refraction is involved and the mode of dealing with this is discussed. Some general remarks in part 6 terminate the paper.

36. *Harmonic Analysis of Gravity Observations.*
A. J. Hoskinson, Trans. Am. Geophys. Un., Vol. 32, No. 2, pp. 163-165, April, 1951.

Gravity meter design has been improved in recent years so that it is now possible to measure accurately the small variations in gravity caused by the tidal forces. Some precise gravity surveys could no doubt be improved by applying corrections for the tidal effect and thus reducing all observations to a common datum.

More information is needed about the possible variations in the tidal forces from place to place on the earth tidal corrections can be applied with assurance to area surveys. A. van Weelden of the Shell Oil Co. initiated a project in 1949 to measure the tidal variations at several stations throughout the world. The results from these observations are available for study by scientists interested in this subject. The harmonic analysis of some of the observations are also available and are presented.

MAGNETIC — GENERAL

37. *Pakistan Survey Begins.*

Oil & Gas Journal, Vol. 50, No. 22, p. 161, October 4, 1951.

A 73,000 sq. miles airborne-magnetometer survey in Pakistan and India was begun October, 1951, by Standard Vaccuum Oil Co.

The first magnetic survey to be conducted by air in Asia, the project will seek magnetic data on rock conditions in the vast alluvial plain of the Bengal basin, which includes the Ganges river delta at the head of the Bay of Bengal.

38. *Geomagnetic Survey of a Portion of Southeastern New York State.*

R. E. Geyer, Geophysics, Vol. 16, No. 2, pp. 228-259, April, 1951.

A geomagnetic survey, using an Askania magnetometer, of portions of northern Westchester, Putnam and Dutchess counties in New York state totaling approx. 130 sq. miles is described and more than 500 observations of the vertical component of the earth's magnetic field are analysed. These data are plotted on a scale of 1 : 30,000 and the resulting isogam chart is used to correlate the observed major changes in the vertical component with variations in the geology of the area in which basement complex rocks outcrop.

This survey demonstrates that a well defined relationship exists between changes in the vertical component values and the major geologic characteristics, using an average (regional) station spacing of four stations per sq. mile. In addition, the probable presence, on the basis of the magnetic data, of additional unexposed amphibolite lenses and associated igneous intrusives is indicated in those areas of the Eastern Schist zone where the glacial overburden and/or soil obscure the underlying formations. The use of statistical methods is demonstrated for evaluating magnetic data for various purposes including the determination of interformational boundaries and the correlation of pronounced changes in geologic and magnetic characteristics.

39. *Flying Magnetometer Survey Completed in Venezuela.*

World Oil, Vol. 132, No. 7, p. 258, June, 1951.

Aerial magnetic studies of a 600 sq. mile area near the southern part of the Gulf of Venezuela were completed recently for Venezuelan Atlantic Refining Co. The study is is the first aeromagnetic survey of the area since 1948, and is part of Venezuelan Atlantic's broad exploration programme.

The survey, with aerial reconnaissance performed by Aero Service Corporation, was flown at an altitude of just under 1,000 ft. over a rectangular grid pattern with flight lines spaced at intervals of from approximately 1,000-2,000 yards. Since much of the survey area is under water, the mapping plane towing a high sensitivity magnetometer was guided by Shoran, the electronic plane positioning device.

MAGNETIC — INSTRUMENTAL

40. *New Exploratory Tool.*

P. C. Ingalls, Oil & Gas Jrnl., Vol. 50, No. 4, p. 145, May 31, 1951.

A down-the-hole exploratory instrument which tests have indicated may become an important tool in locating structures favourable to oil accumulation. Developed by Magnolia Petroleum Company research men, it is known as the magnetic-susceptibility logging instrument. The device determines basic magnetic properties of certain types of underground formations. One of its principal values appears to be in providing control data for interpretation of surface or airborne magnetometer surveys by telling the magnitude and extent of magnetic bodies. Heretofore it has been necessary to make certain assumptions regarding magnetic material in the earth and its environment before it was possible to determine the geological features represented by magnetic anomalies.

11. *Magnetic Well Logging.*

R. A. Broding & Colleagues, Geophysics, Vol. 17, No. 1, pp. 1-26, Jan., 1952.

The need for control data in interpretation of surface magnetometer surveys has led to the development of borehole instruments for measuring magnetic susceptibility and total magnetic field in situ. The susceptibility instrument is an alternating current induction device and by separation of the quadrature components, simultaneous recording of the magnetic susceptibility and the electrical conductivity is possible. The susceptibility log has many features that depart from ordinary electric logs.

The instrument has a sensitivity of the order of 1×10^{-6} cgs units and sufficient contrast has been found in the sediments to yield a log of considerable lithologic character. This magnetic character suggests the use of the susceptibility tool in the field of special well logging, particularly for geologic correlation, and for tracer studies.

The general assumption that the magnetic susceptibility of the sediments is sufficiently low compared to basic igneous rocks so that sedimentary rocks have very little effect on surface magnetometer measurements has been verified. Since the magnetic susceptibility and electrical conductivity logs are made with an induction instrument, an electrolyte is not required in the hole, and the logs are independent of the drilling fluid, except that the conductivity log is influenced by highly conductive muds.

The total field log is made with a three element self-orienting saturable core magnetometer that has been developed for borehole use. This log has not been used extensively. In addition to reflecting changes in polarization of the formations, it is influenced by formation susceptibility. Logs have been made of the total field going into and through igneous plugs.

The paper presents examples of these logs along with a brief description of the instruments developed to produce them.

ELECTRICAL

12. *Transient Electromagnetic Propagation in a Conducting Medium.*

J. R. Wait, Geophysics, Vol. 16, No. 2, pp. 213-221, April, 1951.

The transient electrical fields are calculated for several types of step function current sources embedded in a conducting medium. These are developed by the aid of the Laplace Transformation. The types of source element considered are the electric dipole, the magnetic dipole, and the linear grounded current element of finite and infinite length.

13. *New Electrical Survey Method.*

The Petroleum Times, Vol. 55, No. 1419, p. 1174, December 28, 1951.

A new method for locating oil and gas fields—termed 'Longo'—is attracting attention in Alberta. This aims to determine the actual presence of oil or gas by means of electrical currents, in contrast to seismograph operation which can best locate structures favourable to oil accumulation. The method was developed by Dr. F. W. Lee, former chief of the Geophysical Survey Section of the U.S. Bureau of Mines who organised the Bureau's Division of Geophysical Exploration in 1928. Dr. Lee's method works similarly to electric logs in wells already drilled, but he claims to be able to tell by the electrical resistivity method in advance of any drilling whether any gas or oil is present. Several independent oil companies are using the Lee method; some report results that have proved the predictions.

ON THE INTERPRETATION OF GRAVITY DATA *

BY

A. VAN WEELDEN **

> *"Hope springs eternal in the human heart."*
> Pope

A review of the more recent literature on the geological interpretation of gravity data reveals that there are primarily two schools of thought.

One school tries to derive a mass distribution that would explain the observed anomalies with the use of precise mathematical methods, eliminating all personal equation or bias.

The other school stresses the well established fact that there are an infinite number of possible solutions equally acceptable from a purely mathematical viewpoint and that other considerations, especially geological ones are needed to choose between these various alternatives.

It will be my privilege to give my views on the subject in the following discourse.

In recent years two methods of calculation have drawn a great deal of attention.

The first one is usually referred to as the "second derivative method", the second one as the "continuation or downward projection method". A third one can be added, though not strictly of the same type; e.g., the mathematical systems devised for computing the "regional correction".

The second derivative method was probably first published by Keans (*Geophysics,* July 1938) who wrote, "An introduction to the second derivation contour method of interpreting Torsion balance data".

Some difficulties in the practical application were pointed out among others by Elkins (*Geophysics,* January 1951). He states, "The second derivative method of interpreting gravity data, although its use is justifiable only on data of high accuracy, offers a simple routine method of locating some types of geologic anomalies ..." He thereby limits the applicability in three ways: Firstly, he stresses rightly the need of high accuracy of the data; secondly, he limits the use to some type of anomalies; and, thirdly, he limits the application to the location of anomalies, leaving the actual interpretation of the anomalies out of his considerations.

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* Presidential address delivered at the Second Annual Meeting of the European Association of Exploration Geophysicist, held in Paris on 20th-22nd May, 1953.

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With these restrictions clearly in mind, the method may indeed in certain instances be helpful as a visual aid to spot smaller anomalies superimposed on larger effects.

As a matter of fact, similar methods were already tried by Prof. Schweydar in the late twenties, but this application was not published. Naturally, the usually much greater scatter of the observed points in most areas limited the use of this method even more for the torsion balance, with its greater susceptibility to nearby and purely local disturbances.

The method of downward continuation was probably first described by Evjen (*Geophysics,* January 1936) in his article: "The place of the vertical gradient in gravitational interpretation" and later by Hughes (*Geophysics,* April 1942), Skeels *(Geophysics,* January 1947), Bullard and Cooper (Proceedings Royal Society, A 1948), Henderson and Zietz (*Geophysics,* October 1949), Elkins (*Geophysics,* January 1951), to mention only some of the authors.

This method is based on the principle that if a gravity field or, for that matter, any other potential field is known in a certain plane, the field can be computed for any other plane and by projecting downward we can obtain results as if a survey was made at some subsurface level. In aeromagnetic work this principle is applied to eliminate the need of more than one survey of the same area at different flying altitude.

In making such calculations the resolving power of the gravity data can be improved and by repeating the procedure finally a depth can be reached where the data became inconsistent, indicating that the gravity field is discontinuous, or in other words that the interface has been reached where a density contrast exists. Naturally—by this type of calculation also—the field has to be known accurately and the value decreases considerably with the degree of accuracy of the field work and the density of the observational network.

This depth calculation of the interface is of the greatest importance, but if we examine the problem more closely we can see many falacies. In fairness to the authors, it must be stated here that in most articles some warnings are given and no one should be accused of ignoring completely an obvious truth.

Bullard and Cooper in their above-quoted article on "The Determination of the Masses Necessary to Produce a Given Gravitational Field" start out with the purpose to devise a method for "the direct calculation of the masses from the anomalies", but say later on, "The problem is clearly indeterminable, for, by a theorem due to Green, any mass can be replaced by a suitable distribution at any shallower depth without affecting the field at the surface."

Skeels brings out the falacy of a calculated unique interpretation even clearer and more exhaustively. In fact, it would be a repetition of his arguments if I would discuss this point further.

One must accept the fact that any field can be caused by an infinity of mass distributions and that it is therefore entirely illusory and wishful thinking to try to compute by purely mathematical methods directly and unambiguously from the observations the actual mass distribution.

In their conclusions Bullard and Cooper state, "... the methods developed ... are practicable and may be frequently useful. It may be desirable, however, to emphasize that they do not always repay the considerable mathematical work involved ... and that the main use of the method is in setting a limit to possible depth of the masses." Not only do these methods give us only a limiting maximum depth instead of the actual one, but for various reasons the figures calculated are too large.

One reason, and time does not permit me to mention others as well, is that many authors like to work with such conceptions as line- or point-sources, considering the masses causing the anomalies as concentrated in their center of gravity. For the geological interpretation this introduces a further undesirable element. Translating these sources into actual bodies of rocks and depending on the known or assumed specific gravity differential, the mass can be made larger or smaller within certain limits. This affects the top of the rock body as well and geologically it is just this interface in which we are mostly interested.

In view of these and various similar considerations, I feel that unless very easy and quick calculation methods using modern calculating machines, for instance, can be used, the application of such abstract mathematical calculations is of little practical value. Similar approximations can be obtained in many instances by the use of rule of thumb methods. Jung described several of such methods in his paper read at our London meeting in 1952 and published in the first issue of Geophysical Prospecting.

A great deal of elaborate calculation work can in this manner be avoided, and, moreover, the risk is eliminated that third parties attach too great a value to results of calculations without realizing the weakness of the premises on which they are based.

As Skeels points out, these methods are naturally equally falacious if we would take the results as definite. Their value is to be found in the fact that they enable less experienced interpreters to get more quickly some idea about a possible interpretation. More experienced men will apply these rules almost subconsciously.

This brings me nearer to a description of what I do consider the proper attack for the interpretation but before describing this, I like to remark that, although the picture so far seems to be very gloomy, it can be said in defense of the mathematical school that in favorable cases by using physical principles the possibilities can often be reduced to within fairly narrow limits. I refer to such consideration as, masses cannot overlap; density differentials must be kept within certain reasonable limits, etc.

The most efficient attack of the problem, in my mind, is to consider the gravity data as one of the various sources of information and not as a self-sufficient method. By using all other scraps of information we have, either surface geology, general geological considerations, well data results of other geophysical methods, etc., as well as the gravity data, a guess as to the probable geological situation must be made.

We can then reverse the process and compute the gravity field this situation would cause, and if it does not check within reasonable limits by a process of trial and error, change our conceptions until a reasonable fit is obtained. In view of the many uncertainties, it is a waste of time to continue too long in an attempt to obtain a "perfect fit".

It is in drawing our first "guess" that the rules of thumb and, if easily applicable, some of the more complicated mathematical schemes can be of service, but, as already mentioned, with more experience a good guess is often obtained readily and the need for elaborate calculations decreases.

Actually this method works well when a reasonable amount of other data are available and can be used best to interpolate between or extrapolate from known geological conditions. As the amount or reliability of the available data decreases, and in most reconnaissance surveys only limited information is available, the probability that the "guess" is correct becomes equally smaller. And here we meet with another falacy. Too often gravity interpreters are given only one chance. In exploration, where in practice, and the very nature of the work, we usually deal with the problem of making a "guess" based on insufficient data, nearly every worker is allowed and even forced to review his data whenever more information becomes available. For an unknown reason an exception is too often made for the gravity interpreter. If his first guess is wrong, the data are shelved and he rarely is given another chance. I would like to register a protest against this strange and unfounded tradition and ask for gravity interpreters the same right and duty of review that subsurface geologists, seismologists, paleontologists, and all other members of the prospecting fraternity enjoy.

If practically no other data are available, the gravity interpretation naturally becomes extremely hazardous and the results should be used only as a guide by further exploration. Using a gravity map as an indication of possible trend lines, as a basis for planning seismological or core drill campaigns and thereby limiting the amount of work with more expensive methods or guiding them to places where results may be expected to be obtained quicker, may be of great economic value. A more exact geological interpretation can then be postponed until some results at least are available of these other methods.

In the early days of geophysics it was customary to insist that the geophysicist would give his interpretation of the observations without assistance to check it against known geological data or conceptions and so judge the value of the method. From the foregoing it is obvious that this is for gravity surveys at least completely impossible. It actually amounts to having an interpreter make one guess out of an infinite number of possibilities and if it is not the right one to condemn not only the man but the entire method. It was in those early days customary to use the in itself already ridiculous expression, "in this area the instrument does not work".

I have long believed that this erroneous standpoint had been abandoned and that a reasonable understanding had been reached. If ever co-operation is necessary, it is in the field of gravity interpretation between the gravity interpreter and the geologist. In certain instances the geologist and the gravity interpreter happen to be the same man with training in both branches of the science, but though this may camouflage, it does not alter the fact that co-operation is necessary and one man should not sit in judgment over the other while this second one is barred from information essential for the proper execution of his work.

I regret to say that recently I have experienced that this old idea is not quite dead yet and that even prominent men in the profession fail to understand that bickering between geologists and geophysicists leads us nowhere, but that close co-operation and pooling of resources are imperative.

In the early part of my discourse I mentioned as a third new development the calculation of the regional correction. I may be permitted to make a few remarks on this subject.

This method is especially used in exploration for petroleum. Some of the principles may be applicable in mining geophysics, but I will in the following remarks limit myself to petroleum prospecting.

It is well known and generally accepted that the gravity field is an integral one and combines the influence of all masses. In exploration we are interested in the upper 5 or 6 kilometers of the earth crust only, and it would be most convenient if we could eliminate all deeper effects, and in areas with shallow basement the effects of the latter as well. This wish has led to several proposals to "correct" the observed anomalies for "regional" effects.

It seems to me an often unjustified over simplification to consider regional and local effects only. Many interfaces at various depths may contribute to the gravity field.

In the very early days a third effect was considered. Our tool then was the torsion balance, and more susceptible for purely superficial or near surface disturbances. With the introduction of the less susceptible gravity meter this third effect is largely forgotten, but as Hubbert (*Geophysics,* April 1948) points out, it is still there and unless careful topography corrections are made, as is too often neglected in practice, the accuracy of the observed data is rarely good enough for precise calculations as mentioned before.

However, let us assume that the local effect is negligible and let us further assume that the over simplification of distinguishing between an undesired regional and wished-for local effect is justified. What then is the method we should use for this separation?

In the literature any number of mathematical systems are described to "eliminate the regional" to "correct" for it and "compute" the "residual anomaly". All methods have this in common that over a smaller or larger area a number of points are chosen, either where actual observations were made, or where the gravity values are estimated by interpolation between observed points. The readings at these points are averaged with or without a system of weighting. The value thus obtained is considered the regional correction for the center of the area and subtracted from the observed anomaly to compute the residual.

All these systems are equally ingenuous and leave little between them to choose. They eliminate all personal equation and at first sight seem very attractive.

There are, however, certain objections.

In the first place, the choice of the size of the area. It is often quite possible to make such a choice when working for instance in the central portion of a large basin where the changes in depth to the basement are small compared to this depth.

If we approach the edges or rim of the basin, the disturbing basement masses reach shallower depth and thereby a smaller degree or regionality. They are still equally undesirable contributants to the gravity field. A systematic method would therefore require a variable size of the area over which we average, it becoming smaller in shallower parts of the basin. This is, however, impossible to maintain because near the very rim, close to basement outcrops we would have to reduce the size to such an extent that the desired local structures are thrown out with the regional correction! Even in the twilight zone it is difficult to say when a small regional is not a large local anomaly and vice versa.

A second difficulty is that we do not know for sure what are regional and/or undesirable influences. For instance, on the flank of a basin the sediments may be horizontal and the observed "regional" effect entirely due to the rising basement floor, but in other cases the beds may be inclined, pinch out and contribute to what in any system of averaging would be thrown out as regional correction, whereas this contribution has to do with the desired influence of the sediments.

The difficulty in choosing the size of the area over which one averages to compute the local effect seems to me to be in most cases unsurmountable. Too many mistakes have come to my attention where various authors used correct formulae in the wrong areas, etc., without carefully checking whether or not the premises on which the formulae are based hold true for the new area. In line with what I have said before, I advocate strongly to forget about the objectionable feature of "personal equation" and bias. I believe that a graphical system whereby we can be guided by our geological knowledge is far preferable over the mathematical approach.

A word of warning is, however, necessary. Too often the graphical system is used in a slipshot, easy way. A few "type sections" are drawn, a regional curve is guessed at, and the job is considered completed. Alternatively, a few straight lines are drawn across a map and again the day's work is considered over.

I gladly agree with the mathematical school that such a graphical method is completely unreliable. I would like to compare it with the work of a seismologist who looks once at his record, plots depth data and files his seismogram. Such a man would not hold his job for long. The only way he can get reliable results is by continued study of his records and by comparing them. Similarly, the graphical separation of the large and localized gravity effects should be undertaken by comparing a dense net of sections preferably in two or more directions and by checking and rechecking and using all known geological data to reach a most plausible answer.

I used a moment ago advisedly the word "separation" instead of "correcting" or "elimination". The graphical method definitely cannot be considered infallible. Moreover, we do not a priori know what constitutes "regional" in the sense of undesirable effects and what is residual or desired effect. I am therefore firmly convinced that in studying and interpreting gravity data both the regional and local influence maps must be used continuously and side by side with the original one.

As our understanding of the geology of the area increases, we may want to change the separate maps. We even may want to make further separations, and arrive at a series of several maps, each one depicting influences of different horizontal extent.

I fear that the terms "regional correction" and "computed residual" are too much ingrained in the vernacular of the average geophysicist and dare not hope that they'll be dropped, but I do hope that in future work more and more gravity interpreters will realize that no "correction" has been computed which once applied can be shelved and forgotten.

In the foregoing I have tried to explain some of my objections against a purely mathematical treatment of gravity data. In view of Green's theorem quoted by Bullard and Cooper and by Skeels and others, I cannot but feel that everybody should not only pay lipservice to the fact that no unique mathematical solution is possible, but make it really a part of his interpretative thinking. The gravity method like all geophysical ones is one tool in the arsenal of the prospector. To ignore this and try to use it is as a purely physical or mathematical method means diverting it from its purpose and reducing it to a toy for abstract mathematicians. No cleverly thought-up slogan about "personal equation" can alter this.

Prospecting is still an art and through it mathematics and physics are required to understand some of its tools, nature remains varied making any attempt to penetrate her secrets along strictly logical lines illusory. We can rarely apply our mathematics and physics without an entirely unjustified oversimplification. It would be very comforting and easy indeed if this were not the case and if we could feed a number of observations into a machine and get a correct unique answer. The geological approach in its proper application is much more difficult and often even more time consuming than the mathematical approach, but I cannot hold out much hope that some robot will relieve us from this arduous but interesting duty.

„Es wäre so schön gewesen
Es hat nicht sollen sein."

GRAVITY EFFECT OF EARTH TIDES *

BY

B. BAARS **

Abstract

The gravity effect of earth tides was measured simultaneously at 26 stations, with 2 instruments at 3 of the stations. After a description of the stations, the corrections on the measurements are described. The results for the separate measurements are given and it can be stated that, within the accuracy of the measurements $(1 + h - \frac{3}{2} k)$ is very probably constant and has a value of 1.22. If this value is combined with Nishimura's value 0.66 for $(1 - h + k)$, it can be shown that Takeuchi's earth models fit these values provided a value of 2.7 is taken for the surface density of the earth. The importance of a constant value for $(1 + h - \frac{3}{2} k)$ in gravity surveys is pointed out.

I—Introduction

It has been known already for a long time that the attraction of sun and moon on the earth causes a variation of gravity with time. The variation of gravity can be accurately computed at the surface of a rigid earth. However, the earth is not a rigid body, but yields under influence of the attracting forces of sun and moon, resulting in tides in the earth's crust and a variation of gravity with time which differs from the theoretical value for a rigid earth. The ratio d of the gravity variation for a yielding earth to that for a rigid earth depends on the two Love numbers h and k according to the equation $d = 1 + h - \frac{3}{2} k$. On the basis of the assumptions made in this theory and determinations of h and k, the value of d would have to be about 1.2 without phase difference between attracting force and yielding earth. Measurements of d, undertaken previously, have shown that d varies from 0.6 to 2.2. These variations of d are mainly attributed to the gravitational action of the ocean tides and the shifting load of tidal water.

Knowledge of the deformation of the earth's crust is of scientific interest for obtaining information on the rigidity of the earth, but is also of practical importance. This is due to the fact that the modern gravimeters have a small drift and if the tidal gravity effect is accurately known a correction can be applied

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** N.V. De Bataafsche Petroleum Maatschappij.

to the measurements of a gravity survey allowing less frequent returns to base stations than would otherwise be necessary.

It is desirable to have measurements of the tidal gravity effect taken simultaneously at numerous points throughout the world to get a good idea of the deformation of the earth's crust and to exclude possible changes of d with time due to the bending action of a tidal load of sea water (1). In this connection it is important to have the stations as far as possible contrastingly located e.g. near the coast, inland, at high and low altitudes, near major uplifts.

A programme was proposed within the Shell group to take measurements at some 15 stations scattered throughout all parts of the world where gravity operations were in progress. For a period of 14 days gravimeter readings would be made every 15 minutes, commencing at 9.00 hours G.M.T. on May 9, 1949. This programme aroused great interest on the North American continent among other oil companies and scientific circles, with the result that a total number of 26 stations were measured simultaneously in the period from May 9, 1949, till May 23, 1949, including 3 stations having 2 instruments.

II—The Stations and their Measurements

The locations of the stations were chosen mainly near larger towns to prevent difficulties with instruments which need current for the thermostats, but at points selected for freedom from disturbance and extreme temperature changes. Moreover the stations were selected as far as possible near the sea and far from the sea, at high and low altitude, in basins and on shields, to find out how much influence these factors may have. Observers have overlapped for one hour (4 readings) to minimize the personal element in reading the gravimeters. After the measurements had been taken, all information regarding the measurements, latitude, longitude and elevation of the stations, local times and unusual behaviour of the instruments were forwarded to The Hague office of the Shell Group, where the programme originated, for working out in a uniform way. Table I contains some general information on each station, the type of instruments used and the company which performed the measurements.

The following gives some details of the stations and measurements for every station as far as these particulars are known to us.

1. *The Hague, The Netherlands.*

The measurements have been made in the town, in an annex of the main Shell office. Three 6 m long wooden piles were driven into the ground inside the annex and on these piles was placed a heavy round stone block of 50 cm diameter. The gravimeter was placed on this block. This gave a station which was sufficiently free from disturbances except with heavy wind. After every measurement the instrument was clamped. During the observations we obtained some peculiar results which had not been noted with previous measurements at the same place with other instruments. No reason could then be found, but

TABLE I

Station	Country	Latitude	Longitude	Elevation	Type of Gravimeter	Measured by
The Hague	The Netherlands	52° 06' N	4° 19' E	+ 1.68 m	N.A.G. No 106	Shell
Owerri	Nigeria	5° 29.95' N	7° 01.60' E	+ 68.51 m	N.A.G. No 62	Shell d'Arcy
Helwan	Egypt	29° 51' 28" N	31° 20' 19" E	+ 102 m	N.A.G. No 38	Shell
Pladju	Indonesia	2° 53' 58" S	104° 41' 44" E	+ 7.01 m (Lampong level)	La Coste Romberg No 67	"
Balikpapan	Indonesia	1° 16' 28" S	116° 49' 08" E	+ 85.1 m	N.A.G. No 59	"
Sorong I	Neth.New Guinea	0° 52' 25" S	131° 14' 5[illegible]" E	+ 2.63 m (Sorong level)	N.A.G. No 56	"
Sorong II	" " "				N.A.G. No 60	"
Toronto	Canada	43° 39' 39" N	79° 23' 41" W	-	N.A.G. No 74	Univ. of Toronto
Ottawa	Canada	45° 23.6' N	75° 43.0' W	+ 271 ft	N.A.G. No 85	Dom. Obs. of Canada
Edmonton I	Canada	53° 33' 04" N	113° 29' 13" W	+ 2178.182 ft	N.A.G. No 29	U.G. Co. of Canada
Edmonton II	Canada				N.A.G. No 49	" " " "
(Utah) Salt Lake City	U.S.A.	40° 46.6' N	111° 50.8' W	+ 4675 ft	Worden No 16	Univ. of Utah
Fort Morgan	U.S.A.	40° 15' 14" N	103° 48' 37" W	+ 4322.2 ft	N.A.G. No 82	Col. Sch. of Mines
Washington	U.S.A.	38° 53.6' N	77° 2.0' W	0.2 m	La Coste Romberg No 35	U.S. Coast & Geod. Survey
Tulsa	U.S.A.	36° 09' 26" N	95°54'29.2" W	+ 718.5 ft	Western GA No 20	Shell
Albuquerque	U.S.A.	35° 04' N	106° 35' W	+ 5233 ft	Humble	Humble Oil & Ref. Co.
Austin	U.S.A.	30° 17.3' N	97° 44.2' W	+ 579 ft	La Coste Romberg No 25	Univ. of Texas
Beaumont	U.S.A.	30° 3.92' N	94° 11.80' W	+ 29.8 ft	La Coste Romberg No 15	Sun Oil Co.
Houston I	U.S.A.	29° 42' N	95° 26' W	+ 61.25 ft	La Coste Romberg No 20	Shell
Houston II	U.S.A.				Worden No 10	"
Pasadena	U.S.A.	34° 8.9' N	118° 10.9' W	+ 295 m	La Coste Romberg No 76	Univ. of Cal.(U.C.L.A.)
Honolulu	Hawaii	21° 18' N	157° 52' W	+ 50 ft ± 20 ft	La Coste Romberg No 117	La Coste and Romberg
Panuco	Mexico	22° 10' N	98° 10' W	+ 6 m	Mott Smith No C 15	Pemex
Cosoleacaque	Mexico	17° 58' 03" N	94° 42' 36" W	+ 66.82 m	Mott Smith No C 31	"
Muna	Mexico	20°28'05.8" N	89°42'39.3" W	+ 20.64 m	Mott Smith No C 15	"
Point Fortin	Trinidad	10° 10' 37" N	61° 40' 39" W	+ 60.35 ft	La Coste Romberg No 60	Shell
Maracaibo	Venezuela	10° 40' 26" N	71° 36' 00" W	+ 32.71 m	La Coste Romberg No 72	"
Puerto Colombia	Colombia	11° 00' 30" N	74° 57' 08" W	+ 15.70 m	Carter Oil No 12-Y 1	"
Bogotá	Colombia	4° 38' 39" N	74° 03' 55" W	+ 2589 m	Carter Oil No 36-Y-1	"

subsequently we found that the heat of one of the radiators had not been screened off completely, giving a one-sided heating and resulting most probably in a warping of parts of the instruments.

2. *Owerri, Nigeria.*

Observations were made in the store room of a bungalow at the main camp. This bungalow is situated in flat country in the middle of the camp clearing. The gravimeter was clamped after every reading until May 11 at 13 hours and thereafter the instrument was left unclamped. After two jumps had occurred, for which no reason could be found, the instrument was clamped again after every reading from May 18 at 17.25 hours till May 19 at 17.45 hours. Then the gravimeter was again left unclamped and nothing unusual occurred.

3. *Helwan, Egypt.*

By kind permission of the Director of the Helwan Observatory, which is situated about 25 to 30 km South of Cairo, the observations could be made in one of the buildings of this Observatory. Although the outside temperatures showed large fluctuations, the temperature inside the building remained nearly constant. The gravimeter was set up on a triangular concrete block and left unclamped during the whole period. Every precaution was taken to prevent difficulties from desert sand and dust. Except for a heavy explosion in a limestone quarry, 400 m from the point of observation, which showed no influence on the observations, no troubles of any kind were experienced.

4. *Pladju, Indonesia.*

A concrete block on the airfield Talang Betutu, roughly 10 km North-West of Palembang, selected as main base point for gravimeter surveys in this neighbourhood, had been chosen as observation point. This airfield is on somewhat higher ground than the surroundings. The gravimeter was left unclamped and only a slight jump occurred, due to bumping against the instrument.

5. *Balikpapan, Indonesia.*

The instrument was set up on a concrete block in the building of the Geological Department of the B.P.M. On May 12 and 13 some rather irregular readings were obtained without any known cause. After every reading the instrument was clamped.

6, 7. *Sorong I and II, Netherlands New Guinea.*

The two instruments were set up next to each other on a concrete block about 500 m from the coast. The station was in the open, but during the measurements a tent was used. It was free from artificial or wind disturbances and no influence of wave action on the coast was noticeable. The gravimeters were left unclamped.

N.B. The stations following hereafter were measured with unclamped instruments, if not stated otherwise.

8. *Toronto, Canada.*

The gravimeter was set up on a concrete pier in the basement of the Observatory on the University campus. The following paragraph has been quoted from the letter accompanying the measurements:

"On May 13 at 10.28 hours G.M.T. the reading of the gravimeter was found to have dropped considerably, and it continued to drop over a period of more than one hour. A new observer arrived at 12.00 and noticed that both level bubbles were about 1 division away from their correct positions, while the meter itself appeared to have moved from its previous position on the stand. On correcting the level, the reading returned to a value consistent with the readings taken before 10.28. I do not believe that the continued drop can be explained by a single jolting of the meter, but rather by a continued tilting. It is not known why or how this can have occurred."

The drop of the gravity value mentioned between 10.28 hours and 11.30 hours on May 13 amounted to 0.2 mg.

9. *Ottawa, Canada.*

The instrument was placed on a concrete pier in the basement of the Dominion Observatory. The measurements showed some irregularities on May 12, before the batteries for the thermostat of the instrument were changed at 20.53 hours. A correction has been applied to the readings between 12.00 hours and 21.00 hours on that day.

10, 11. *Edmonton I and II, Canada.*

Two gravimeters were set up on the concrete ground floor of the Edmonton Technical Building. This place was very stable and free from wind and traffic disturbances.

12. *Salt Lake City,* U.S.A.

The gravimeter was placed in the Seismograph Laboratory on the campus of the University of Utah. The meter sensitivity was changed between 18.00 hours and 18.30 hours on May 11. This shifted the zero position, causing a discontinuity in the curve. A correction was applied for both zero shift and change in sensitivity.

13. *Fort Morgan, U.S.A.*

The station was located in the basement of the Rambler's Hotel. On May 15 difficulties were encountered with a relay giving some irregular readings. Two jumps occurred, one on May 11 and one on May 22.

14. *Washington, U.S.A.*

The observations were made at the Washington gravity base station in the pendulum room of the Department of Commerce.

15. *Tulsa, U.S.A.*

The place selected for the measurements was on a concrete floor of a private garage. The following statement was made:

"The station was free from traffic and other disturbances, but was subject to greater temperature variations than desired, the maximum variation being 10° C over a 24-hour period, but this variation does not appear to have materially affected the results except in one case (May 21) when a tornado was nearby and the barometric pressure and temperature both dropped and then rose suddenly. It was also noted that the meter reading was changed by about 0.015 mg whenever the thermostat lights came on. When this was discovered, all subsequent readings were taken when the thermostat lights were off."

16. *Albuquerque, U.S.A.*

The location of the station was Apartment No 15 of the Ambassador Lodge. The meter was clamped between the readings to avoid excessive drift and the instrument was read to ½ scale division, one scale division being 0.1 mg.

17. *Austin, U.S.A.*

The instrument was set up in the Physics Building of the University of Texas. The gravimeter was photographically recorded. The continuously recording mechanism moved with a speed of 1 cm per hour. The record was read every half hour except where $\triangle g$ was going through a minimum or maximum and then it was read every 15 min. The readings were made to the closest mm (1 mm = 0.001068 mg). On May 10 from 19.30 hours till 23.45 hours, on May 19 from 8.30 hours till 16.00 hours and on May 21 from 13.00 hours till May 22 12.00 hours the thermostat was out of control. On May 11 between 14.00 hours and 17.00 hours the meter was readjusted. From 6.00 hours till 16.00 hours on May 12 a bad record was obtained.

18. *Beaumont, U.S.A.*

Nothing to report.

19, 20. *Houston I and II, U.S.A.*

As a suitable location for the readings was chosen the ground floor of Shell Exploration and Production Laboratory. The two instruments were set up next to each other. The Worden meter was given an extra layer for insulation although the building is air-conditioned and temperature fluctuations are small. On May 17 around 5.00 hours, on May 19 at 19.00 hours and at May 22 at 22.00 hours some irregular readings were obtained with the Worden meter without any known cause.

21. *Pasadena, U.S.A.*

The Pasadena Seismological Laboratory of the University of California was selected for the measurements. The instrument was photographically recorded and record readings were submitted. The following information was given:

"For the first week, following procedure successfully adopted at La Jolla, it was tilted longitudinally through two divisions on the level mounted on the instrument. This was excessive and tilt was reduced after the first week to one division, i.e. 1′ tilt. Considerable drift was experienced during the first few days. For this reason certain estimated corrections are suggested for the first week."

We have used the adjusted values. Several times during the first week the instrument "hit bottom".

22. *Honolulu, Hawaii.*

The instrument was set up in the basement room of the University of Hawaii. This University is about two miles from the Ocean. The gravity variations were recorded, because microseism, probably caused by wave action, made use of photoelectric recording very desirable as it averaged out the short period irregularities. Readings from the records were submitted. Two breaks occurred, the first from 18.50 hours on May 14 till 2.20 hours on May 15, the second one from 14.00 hours on May 15 till 0.50 hours on May 16.

23. *Panuco, Mexico.*

Nothing to report.

24. *Cosoleacaque, Mexico.*

On May 19 between 13.00 hours and 16.30 hours the photocell was replaced, changing the base level. On May 21 some rather irregular readings occurred.

25. *Mura, Mexico.*

Nothing to report.

26. *Point Fortin, Trinidad.*

A solid concrete foundation at the Point Fortin ammunition depot was used for the measurements. Only occasional very slight disturbances occurred due to the passing of heavy trucks and possibly also caused by distant drilling operations. In no way did this interfere with the measurements.

27. *Maracaibo, Venezuela.*

The site chosen here for the observations was a cement and brick house "Berta" of the Shell Bella Vista Colony. With the exception of a period of 15 hours at the beginning of the observations the meter was left unclamped. A fault in the cable between battery and instrument on May 21 caused an interruption of several hours, as the instrument became immediately off temperature. A small jump occurred when a piece of wood fell against the instrument.

28. *Puerto Colombia, Colombia.*

This station was located in one of the bungalows of the hotel Pradomar about

70 m from the shore of the embayment. The maximum tide is less than 0.5 m, which gives a negligible effect on the readings. The bay shows practically no waves. The gravimeter was loaned to Shell by the Tropical Oil Company. The following remarks were made regarding the measurements:

"The gravimeter worked very well in the first part of the observations. Later, several jumps occurred without any apparent cause. The instrument appears to have been somewhat sluggish during the second half of the observations so that the maxima and minima look flatter than the previous ones", and "The lamp which illuminates the reading scale frequently burned out and small jumps were produced whenever a new lamp was fitted. The gravimeter was later clamped on such occasions and apparently this clamping did not affect the subsequent readings."

29. *Bogotá, Colombia.*

The station was located in one of the suburbs of Bogotá. The gravimeter was set up on the cement floor approximately 25 m from the street, which had little traffic. Three jumps occurred. From the information received we quote here two paragraphs:

"The gravimeter was loaned to us by the Tropical Oil Company as our North American gravimeter was damaged during the transport between Urabá and Bogotá. When the loaned instrument was tested before the start of the observations by Pineda, who had had previous experience with this type of gravimeter, it showed great irregularity owing to the displaced position of the metal ring used for the determination of sensitivity. By the time this was remedied and the gravimeter tested again, observations could only be started on May 11th, 23.00 hours G.M.T. instead of on the appointed time which was May 9th. A full half period of 14½ days was, however, observed with the instrument."

"The gravimeter had not been in use for a considerable time and showed an extremely large drift during the observations. This drift gradually diminished from 4.4 mgal. in the first 24 hours to 1.4 mgal. in the last 24 hours. According to information received from the Tropical, the normal drift of their gravimeters varies, but is below 0.6 to 0.7 mgal. in a full working day. Apparently the instrument was slowly settling down and the drift would have been probably smaller if a thermo-regulator of less than 45° C could have been used. As this was not possible, the garage was slightly heated in order to diminish the difference between the outside temperature and that of the instrument."

N.B. All times mentioned are Greenwich Mean Times.

III—The Corrections

Three corrections have been applied to the measurements:

a) Correction for personal element in the observers' readings.

b) Correction for jumps of the instrument.

c) Correction for drift of the instrument.

a) As there is a personal element in reading a gravimeter, the observers were asked to overlap by four readings. Where it was obvious that a difference between the readings of different observers existed, a correction was applied. This was only in some cases, because most overlap readings did not show a clear difference of readings between observers and moreover it is very often difficult to judge from only four points whether a real difference exists. As the reading accuracy with most instruments will not be better than 0.01 mg only differences of 0.03 mg or more were applied as corrections.

b) The measurements of a number of stations showed jumps of the instrument or a difference between two successive readings which was 0.03 mg or more and which did not return to normal in the following readings. In such a case a smooth curve was drawn through the points on both sides of the jump and the jump correction determined.

c) When these two corrections had been applied, the drift of the instrument had to be determined. The tidal gravity effect can be written as the sum of a number of terms, each containing a simple harmonic function. The periods of each of the main terms or partial tides are all nearly equal to 12 or 24 hours. If the periods would have been exactly 12 or 24 hours, the average of the readings for 24 hours would always be constant throughout time. Thus if the 24 hours average changes with time, this is due to drift of the instrument. As the periods differ only slightly from 12 or 24 hours a smooth curve drawn through the running 24 hours averages will represent the drift curve quite well. The 24 hours average was determined for every 6 hours and in this way the drift curve was drawn. This curve was subtracted from the measured curve, already corrected for the personal element in reading and the jumps giving the corrected measured curve. The possibility that the drift curve contains 12 or 24 hours periods seems to be small.

One remark may be made: The gravity meter readings should also be corrected for acceleration due to the movement of the earth's crust. But a very easy calculation shows that this effect can be neglected.

IV—THE RESULTS AND THEIR ACCURACY

The corrected measured curve has to be compared with the theoretical curve for a rigid earth. Values for these theoretical curves have been calculated for every hour by using the formula for the attraction of sun and moon (2):

$$C_{s,\,m} = f_{s,\,m}\, K_{s,\,m}\, (\cos^2 Z_{s,\,m} - \frac{1}{3}).$$

This formula has been represented in nomograms (3) and making use of an Air Almanac in addition to the nomograms, these calculations become very easy. The values are plotted on the graph of the corrected measured curve and a curve is drawn through the plotted points. The theoretical and the observed curves are then compared in amplitude and phase. On the basis of the theory of Love the ratio of the amplitudes should be about 1.2 and no phase difference between the two curves should exist. Maxima and minima of both curves are marked and from these amplitudes and phases are read. Similar amplitudes of both curves are plotted in fig. 1. The ratio of the amplitudes for the value d is determined by the tangent of the angle which the straight line through the origin and the plotted points makes with the horizontal axis. To get a better idea of this value d, new graphs were made (fig. 2) in which the ratio of observed over theoretical value of the amplitudes has been plotted against the value of the theoretical amplitude. As the accuracy of d decreases when the amplitudes become smaller, an average value was calculated taking the weight of every value d equal to the value of the theoretical amplitude, which seems a reasonable assumption. To check this assumption an average value for d was also determined, leaving out all points where the theoretical amplitude was smaller than 0.10 mgl. A compilation of all values has been given in Table II. The values of the larger amplitudes are somewhat more accurate because the standard deviations are smaller.

As can be seen from the graphs in figures 1 and 2, some stations give points which line up very well while at other stations the points are much more scattered. This scattering is especially noticeable in the case of the stations Pladju and Bogotá. The value d for station Pladju is very high compared with other stations and although we have no information that anything was wrong, there is a slight indication in the corrected measured curve that a temperature

(*to be continued on p. 99*)

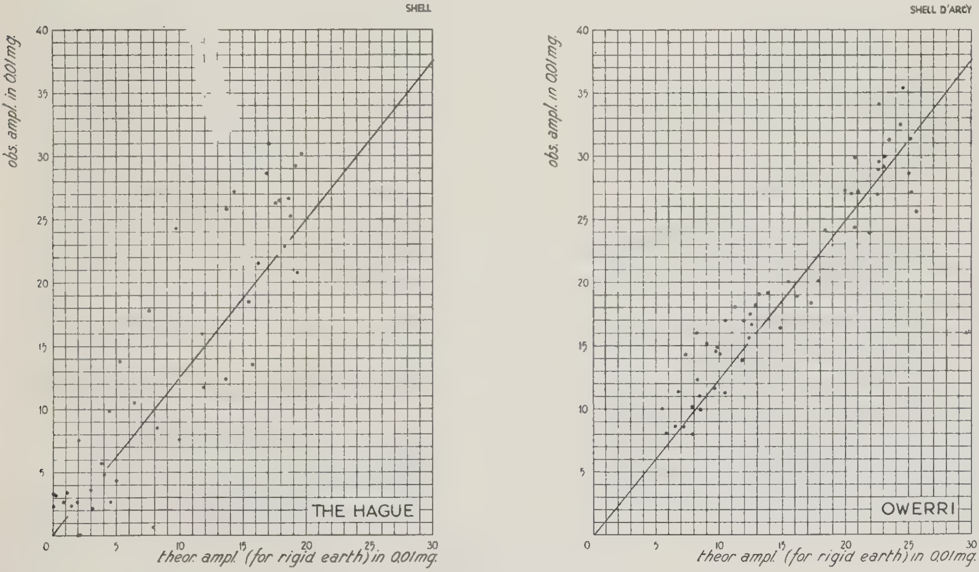


Fig. 1

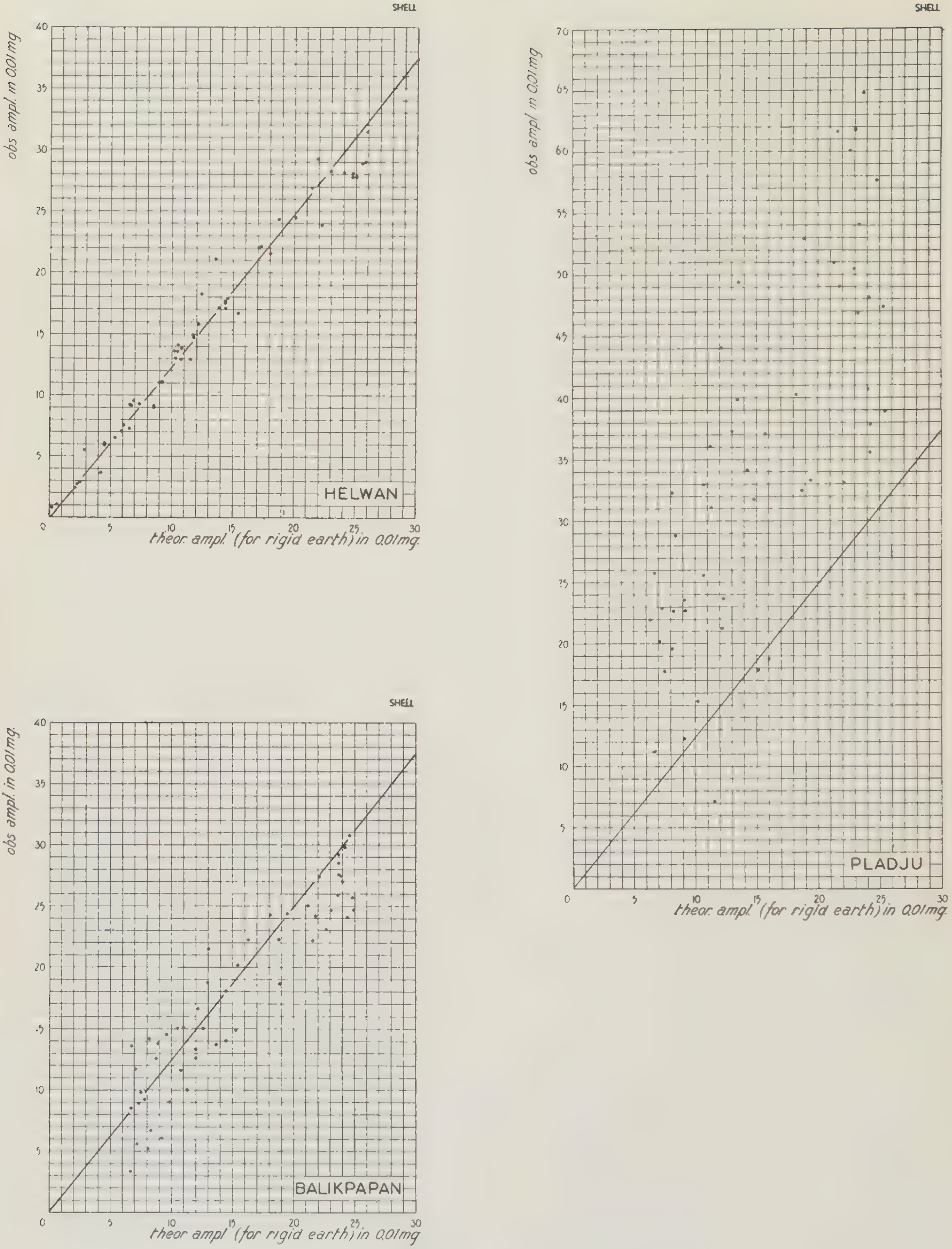

SHELL
obs ampl. in 0.01 mg
HELWAN
theor. ampl. (for rigid earth) in 0.01 mg.
SHELL
obs ampl. in 0.01 mg
PLADJU
theor. ampl. (for rigid earth) in 0.01 mg.
SHELL
obs ampl. in 0.01 mg.
BALIKPAPAN
theor. ampl. (for rigid earth) in 0.01 mg

Fig. 1 (cont'd)

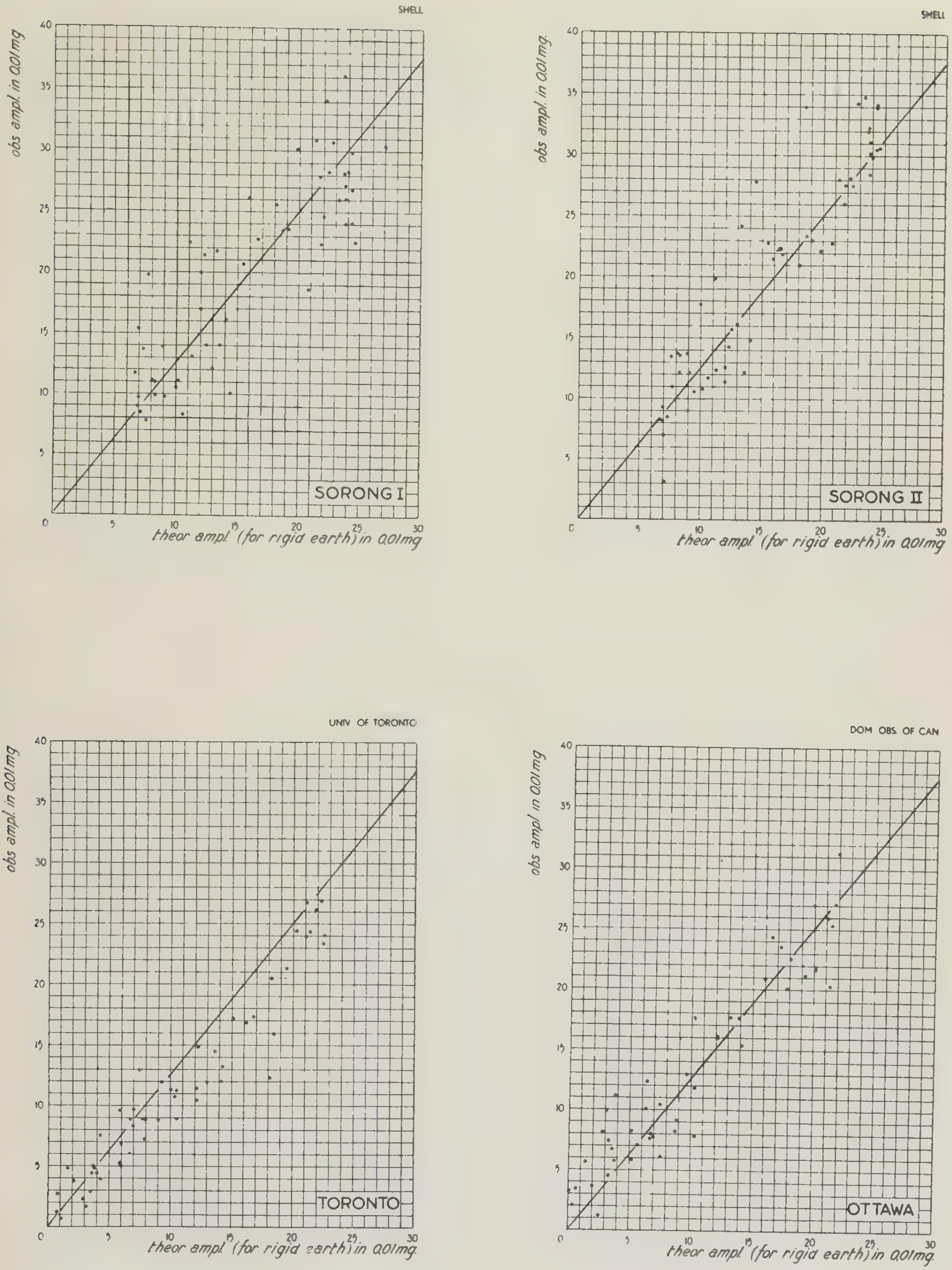

SHELL
obs ampl. in 0.01mg
0
5
10
15
20
25
30
35
40
theor ampl. (for rigid earth) in 0.01mg
SORONG I
SHELL
SORONG II
UNIV OF TORONTO
TORONTO
DOM OBS OF CAN
OTTAWA

Fig. 1 (cont'd)

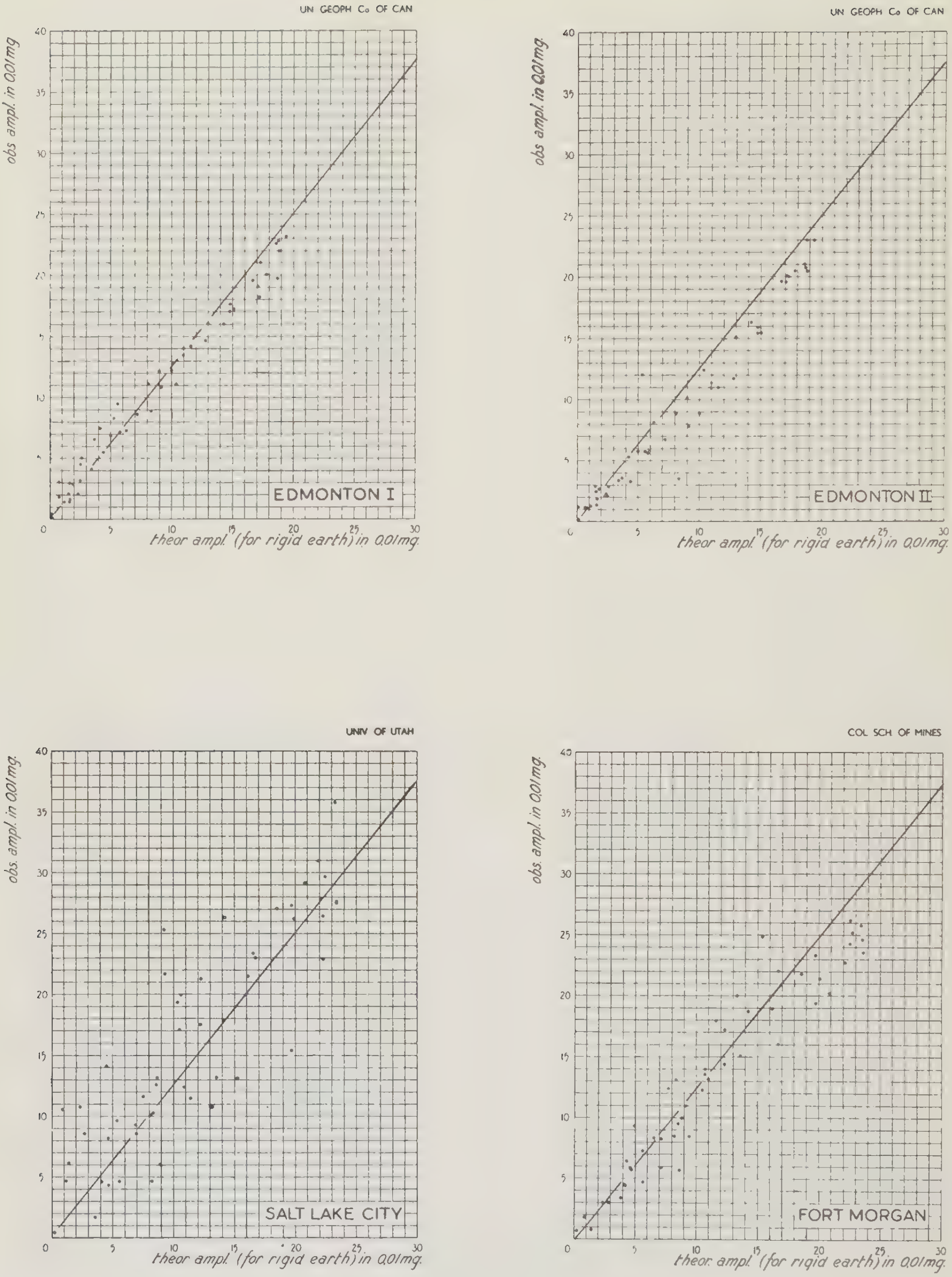
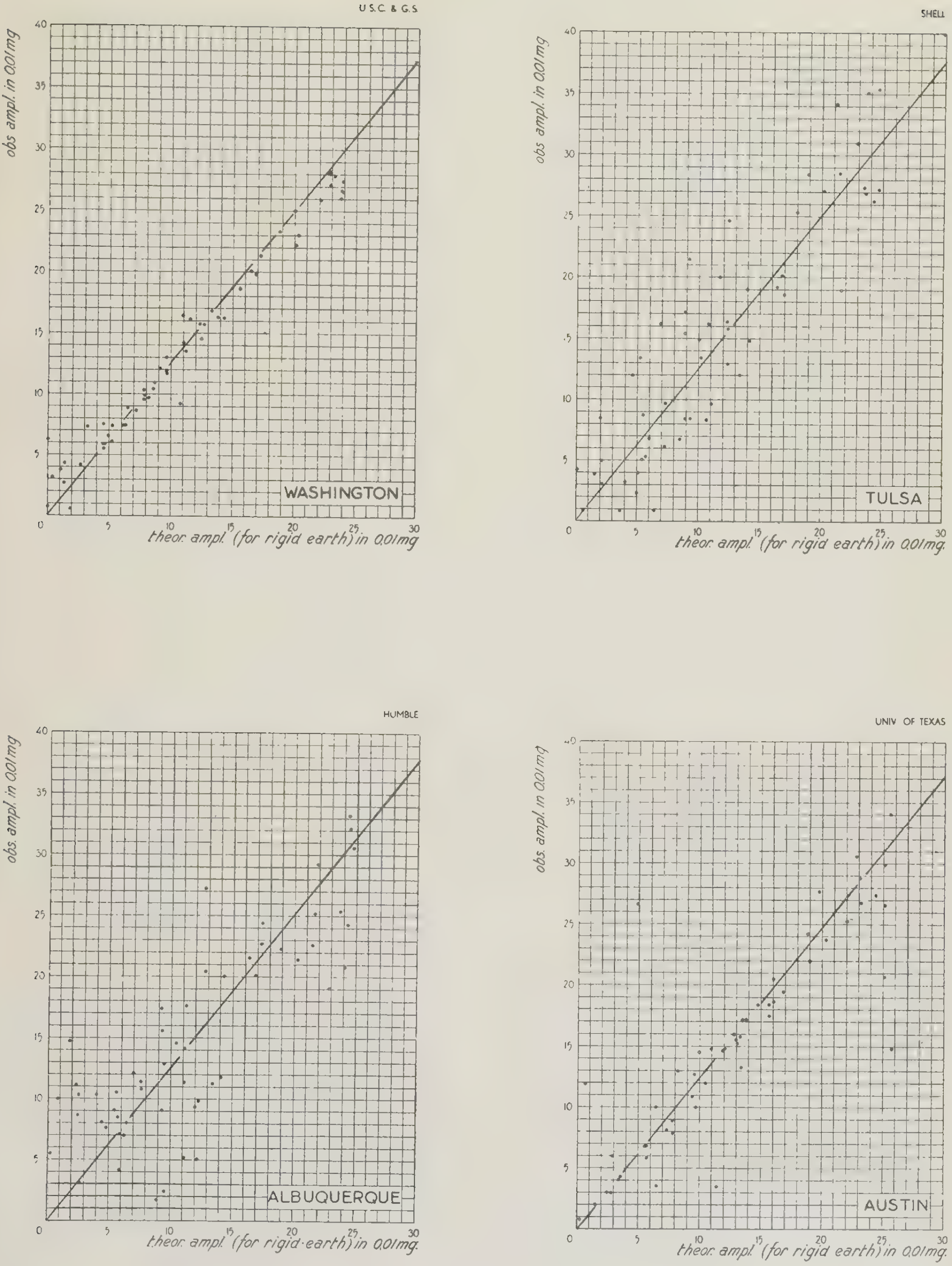

UN GEOPH Co OF CAN
obs ampl. in 0,01mg
theor ampl. (for rigid earth) in 0,01mg
EDMONTON I
UN GEOPH Co OF CAN
obs ampl. in 0,01mg
theor ampl. (for rigid earth) in 0,01mg
EDMONTON II
UNIV OF UTAH
obs. ampl. in 0,01mg.
theor ampl. (for rigid earth) in 0,01mg.
SALT LAKE CITY
COL SCH OF MINES
obs. ampl. in 0,01mg
theor. ampl. (for rigid earth) in 0,01mg.
FORT MORGAN
0
5
10
15
20
25
30
35
40

Fig. 1 (cont'd)


U.S.C. & G.S.
WASHINGTON
SHELL
TULSA
HUMBLE
ALBUQUERQUE
UNIV OF TEXAS
AUSTIN
obs ampl. in 0.01mg
theor. ampl. (for rigid earth) in 0.01mg
0
5
10
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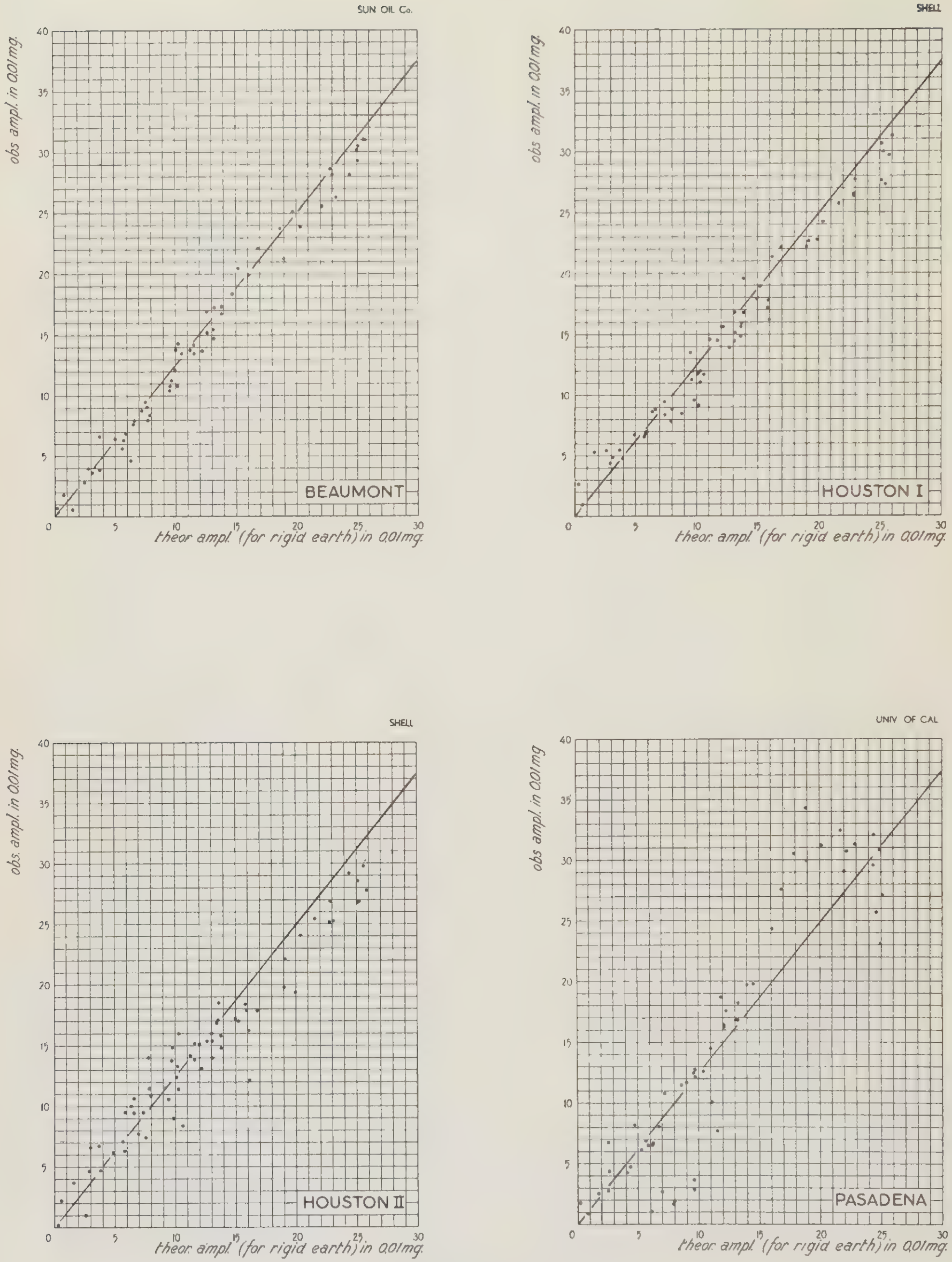
40

Fig. 1 (cont'd)


SUN OIL Co.
BEAUMONT
SHELL
HOUSTON I
SHELL
HOUSTON II
UNIV OF CAL
PASADENA
obs ampl. in 0.01mg.
theor. ampl. (for rigid earth) in 0.01mg.
0
5
10
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25
30
35
40

Fig. 1 (cont'd)

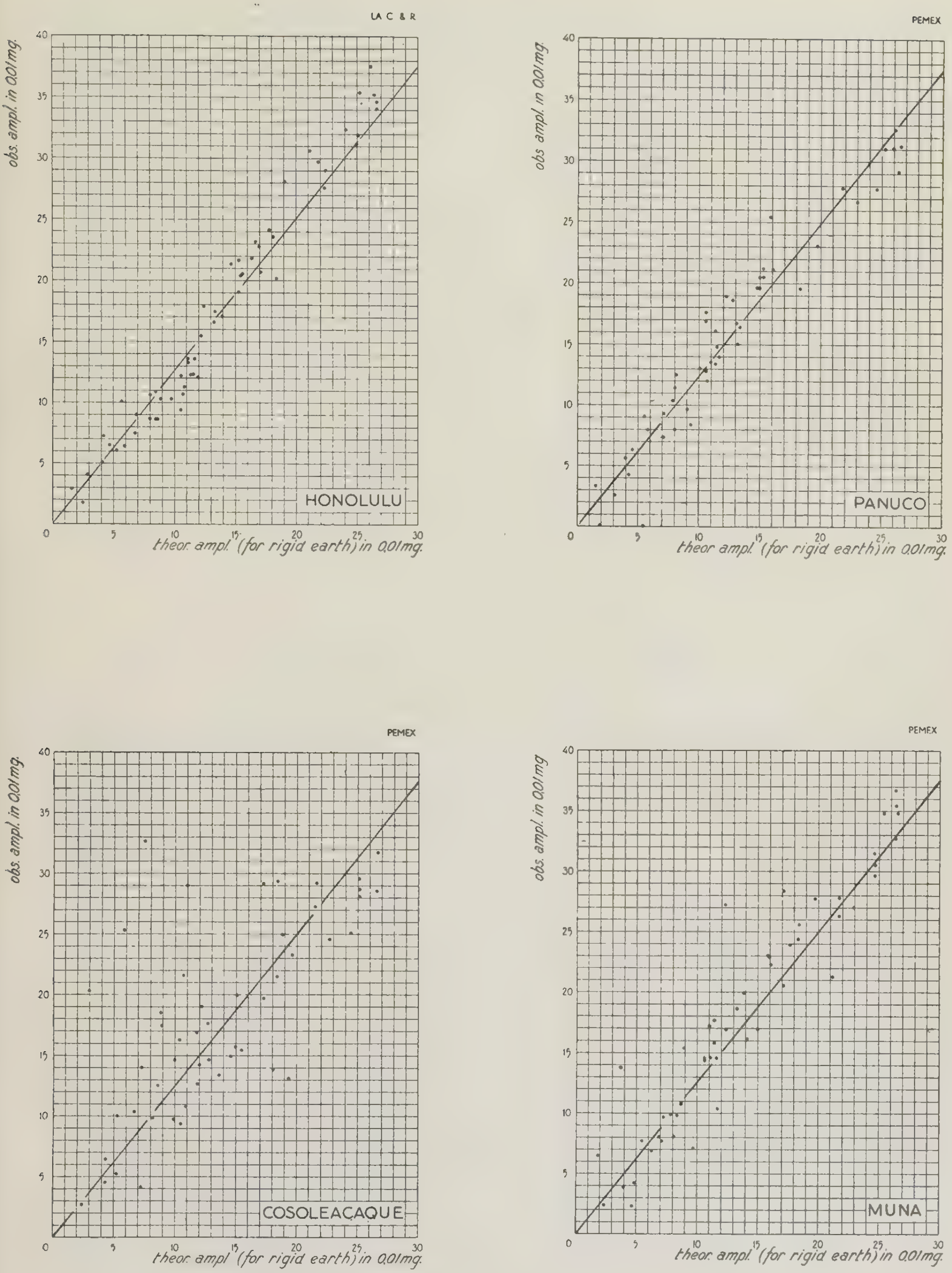
LA C & R
HONOLULU
PEMEX
PANUCO
PEMEX
COSOLEACAQUE
PEMEX
MUNA
obs. ampl. in 0.01mg.
theor. ampl. (for rigid earth) in 0.01mg.
0
5
10
15
20
25
30
35
40

Fig. 1 (cont'd)

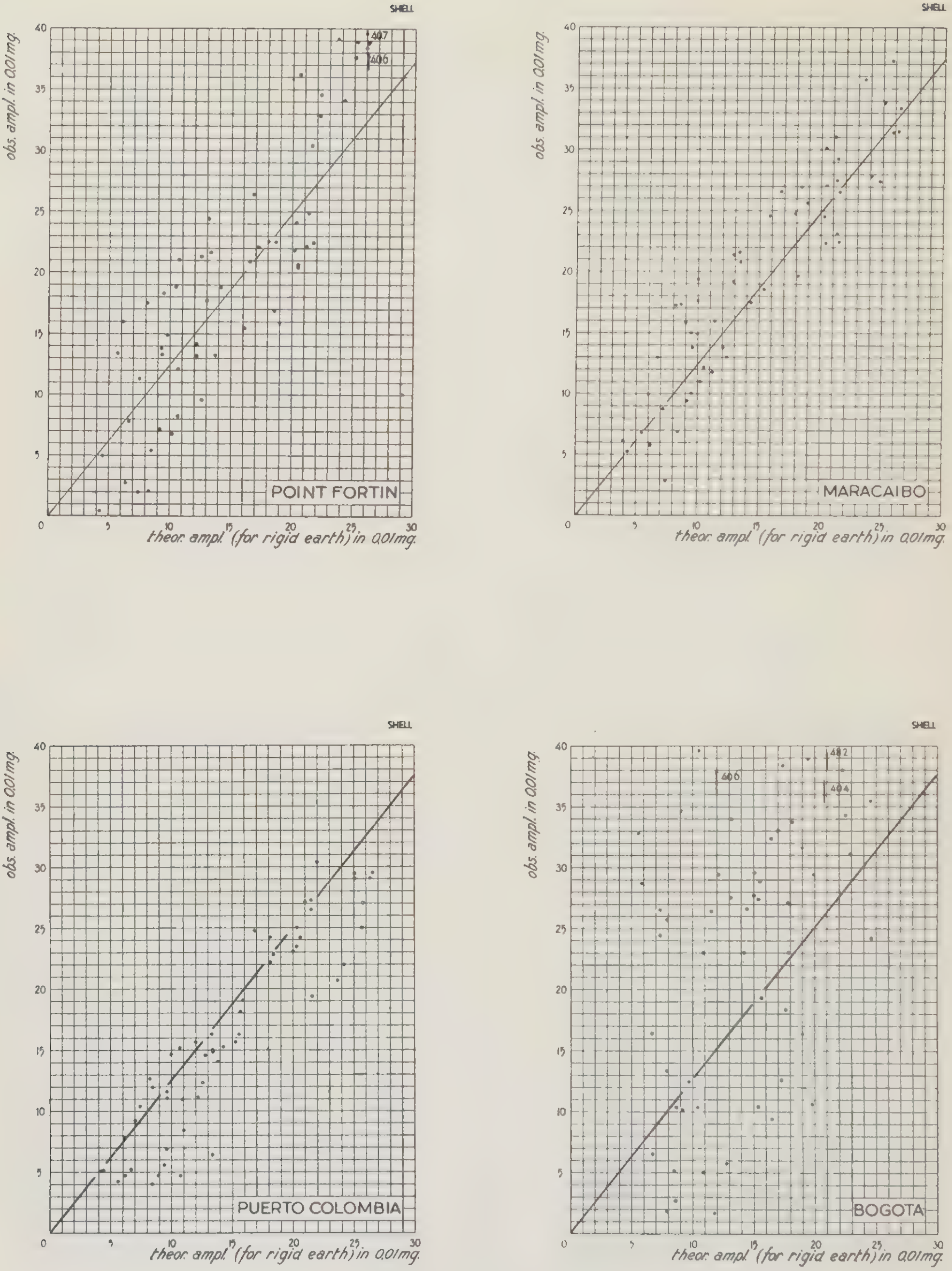
SHELL
obs. ampl. in 0.01 mg.
theor. ampl. (for rigid earth) in 0.01 mg.
0
5
10
15
20
25
30
35
40
407
406
POINT FORTIN
MARACAIBO
PUERTO COLOMBIA
BOGOTA
402
404

Fig. 1 (cont'd)

(continuation of p. 91)

Station	Theor.ampl. > 0.00 mgl			Theor.ampl. ≥ 0.10 mgl			Every min. and max.			Min. or max. between two ampl. each ≥ 0.10 mgl		
	Average value d	Standard deviation	Number of Observ.	Average value d	Standard deviation	Number of Observ.	Average phase diff. φ in min.	Standard deviation	Number of Observ.	Average phase diff. φ in min.	Standard deviation	Number of Observ.
(The Hague)	(1.43)	(0.43)	(38)	(1.39)	(0.31)	(18)	(+12)	(51)	(40)	(+24)	51	(11)
Owerri	1.30	0.17	53	1.27	0.15	37	- 1	30	54	+ 8	21	34
Helwan	1.22	0.10	55	1.22	0.10	34	- 4	21	56	- 1	18	24
(Pladju)	(2.26)	(0.69)	(50)	(2.18)	(0.64)	(38)	(- 8)	(126)	(52)	(-45)	(89)	(36)
Balikpapan	1.16	0.19	53	1.16	0.14	37	- 1	29	54	+ 2	20	36
Sorong I	1.24	0.26	53	1.23	0.24	39	0	23	55	- 1	19	38
Sorong II	1.29	0.19	55	1.29	0.17	39	+ 4	28	56	+ 5	24	38
Toronto	1.09	0.19	52	1.06	0.14	25	+ 11	30	53	- 3	19	14
Ottawa	1.29	0.27	47	1.21	0.16	21	+ 2	51	48	+ 6	47	10
Edmonton I	1.22	0.12	49	1.16	0.06	20	+10	38	50	+ 8	27	13
Edmonton II	1.10	0.15	49	1.10	0.09	20	+19	41	50	- 1	21	13
Salt Lake City	1.39	0.41	51	1.30	0.27	26	- 1	62	52	- 8	35	13
Fort Morgan	1.16	0.19	51	1.16	0.16	26	+ 5	31	52	- 4	15	13
Washington	1.23	0.11	55	1.19	0.07	27	- 2	19	56	- 5	14	15
Tulsa	1.30	0.36	55	1.27	0.25	29	+17	59	56	-20	40	18
Albuquerque	1.27	0.46	53	1.16	0.29	28	+29	75	54	+ 4	37	16
Austin	1.19	0.13	55	1.19	0.11	34	+ 8	19	56	+ 8	16	24
Beaumont	1.21	0.08	57	1.22	0.07	34	0	16	58	- 4	9	23
Houston I	1.19	0.10	64	1.18	0.08	40	- 9	19	65	- 2	14	29
Houston II	1.18	0.16	64	1.14	0.10	40	+ 9	29	65	- 2	19	29
Pasadena	1.25	0.31	56	1.33	0.22	29	+14	35	57	+ 5	32	18
Honolulu	1.28	0.13	58	1.29	0.11	40	+24	31	59	+19	29	31
Panuco	1.26	0.16	47	1.27	0.13	32	+ 6	27	40	+ 5	21	23
Cosoleacaque	1.31	0.43	52	1.20	0.24	36	+13	57	53	-15	31	26
Muna	1.32	0.20	53	1.33	0.15	35	-15	42	54	- 2	21	27
Point Fortin	1.32	0.37	55	1.33	0.31	39	+ 4	42	56	+13	30	33
Maracaibo	1.32	0.24	55	1.31	0.20	38	+ 3	29	56	+ 5	20	31
Puerto Colombia	1.10	0.22	56	1.12	0.18	40	-25	50	57	-16	40	35
(Bogota)	(1.68)	(0.81)	(56)	(1.60)	(0.68)	(41)	(-20)	(81)	(57)	(+11)	(49)	(39)
Average for all stations except The Hague, Pladju and Bogota	1.24	0.24	1403	1.22	0.18	845	+ 5	35	1430	+ 2	24	624

+ measured phase leading over theoretical phase
- " " lagging behind theoretical phase

effect may still be present as the larger amplitudes occur mostly around midnight and the smaller ones round noon. Before accepting these measurements therefore, one would like to have confirmation and in Table II the values have been placed between brackets because they seem to be very doubtful. For station Bogotá the points are too erratic to give even a partly reliable value, most probably due to the excessive drift of the instrument. Station The Hague gives also very erratic values, which can be ascribed to an incompletely screened radiator, which was heated up in the morning and cooled off again in the afternoon. A period of about 6 hours can be seen at some days in the corrected measured curve. Previous measurements at exactly the same place have given for d a value of about 1.2 (2). The values for these three stations are thus so doubtful that they have not been taken into consideration in our following

(to be continued on p. 103)

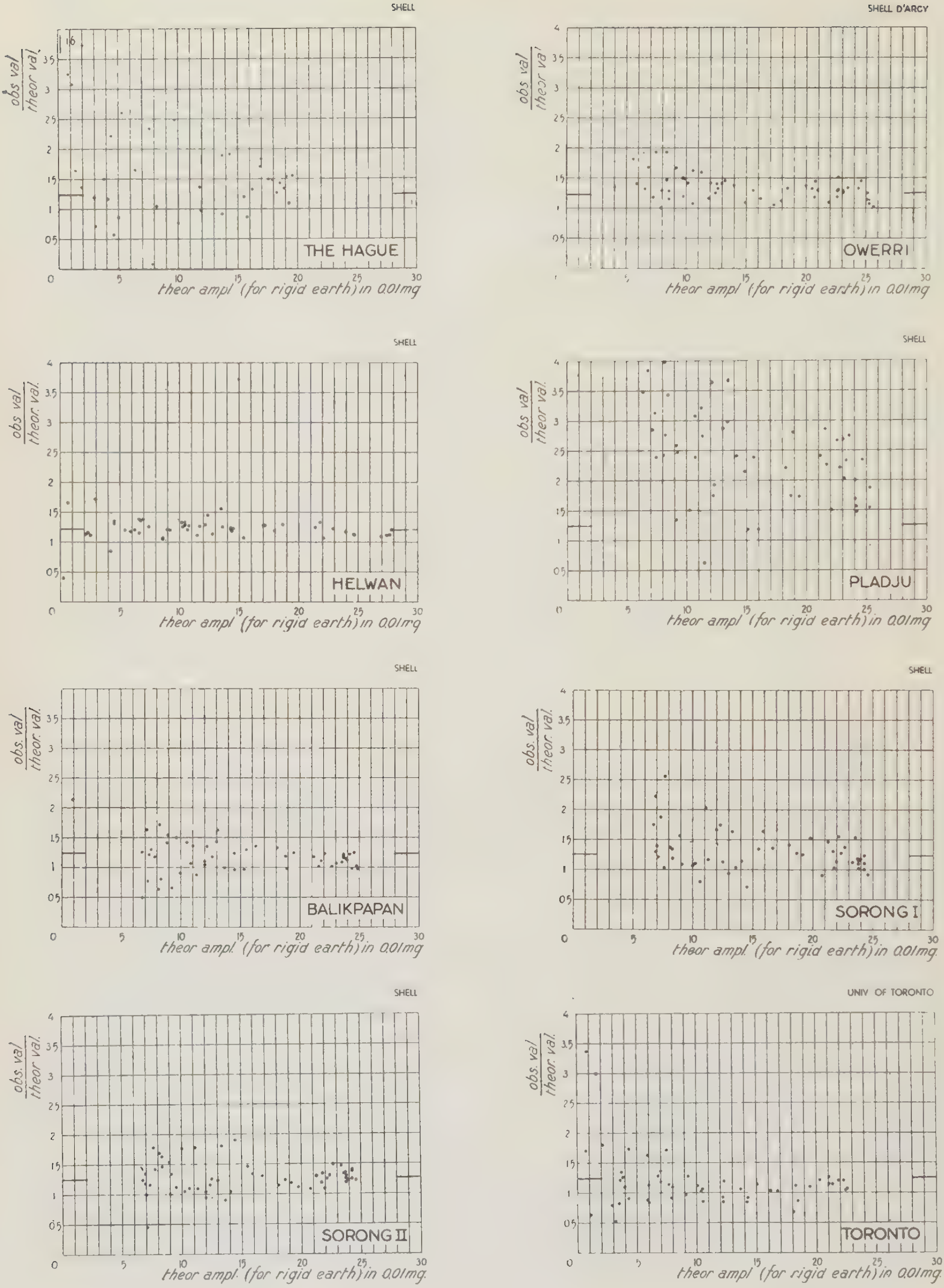
SHELL
SHELL D'ARCY
THE HAGUE
OWERRI
HELWAN
PLADJU
BALIKPAPAN
SORONG I
SORONG II
TORONTO
UNIV OF TORONTO
obs val / theor val
theor ampl (for rigid earth) in 0.01mg
0
5
10
15
20
25
30
0.5
1
1.5
2
2.5
3
3.5
4

Fig. 2

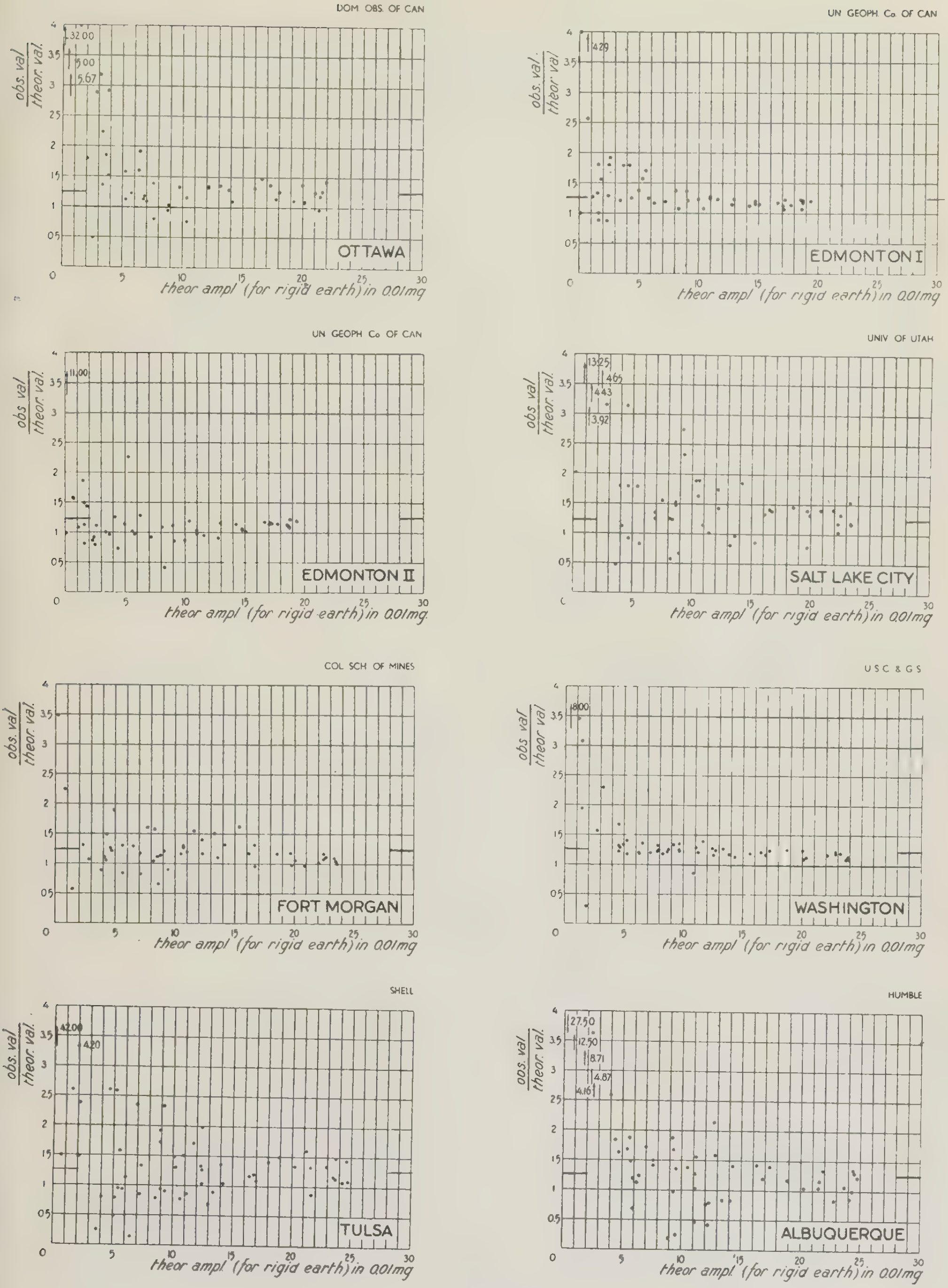
DOM OBS. OF CAN
obs. val / theor. val.
32.00
5.00
5.67
OTTAWA
theor ampl (for rigid earth) in 0.01mg
UN GEOPH. Co. OF CAN
4.29
EDMONTON I
theor ampl (for rigid earth) in 0.01mg
UN GEOPH Co OF CAN
11.00
EDMONTON II
theor ampl (for rigid earth) in 0.01mg.
UNIV OF UTAH
13.25
4.65
4.43
3.92
SALT LAKE CITY
theor ampl (for rigid earth) in 0.01mg
COL SCH OF MINES
FORT MORGAN
theor ampl (for rigid earth) in 0.01mg
U S C & G S
8.00
WASHINGTON
theor ampl (for rigid earth) in 0.01mg
SHELL
42.00
4.20
TULSA
theor ampl (for rigid earth) in 0.01mg
HUMBLE
27.50
12.50
8.71
4.87
4.16
ALBUQUERQUE
theor ampl (for rigid earth) in 0.01mg
0
0.5
1
1.5
2
2.5
3
3.5
4
5
10
15
20
25
30

Fig. 2 (cont'd)

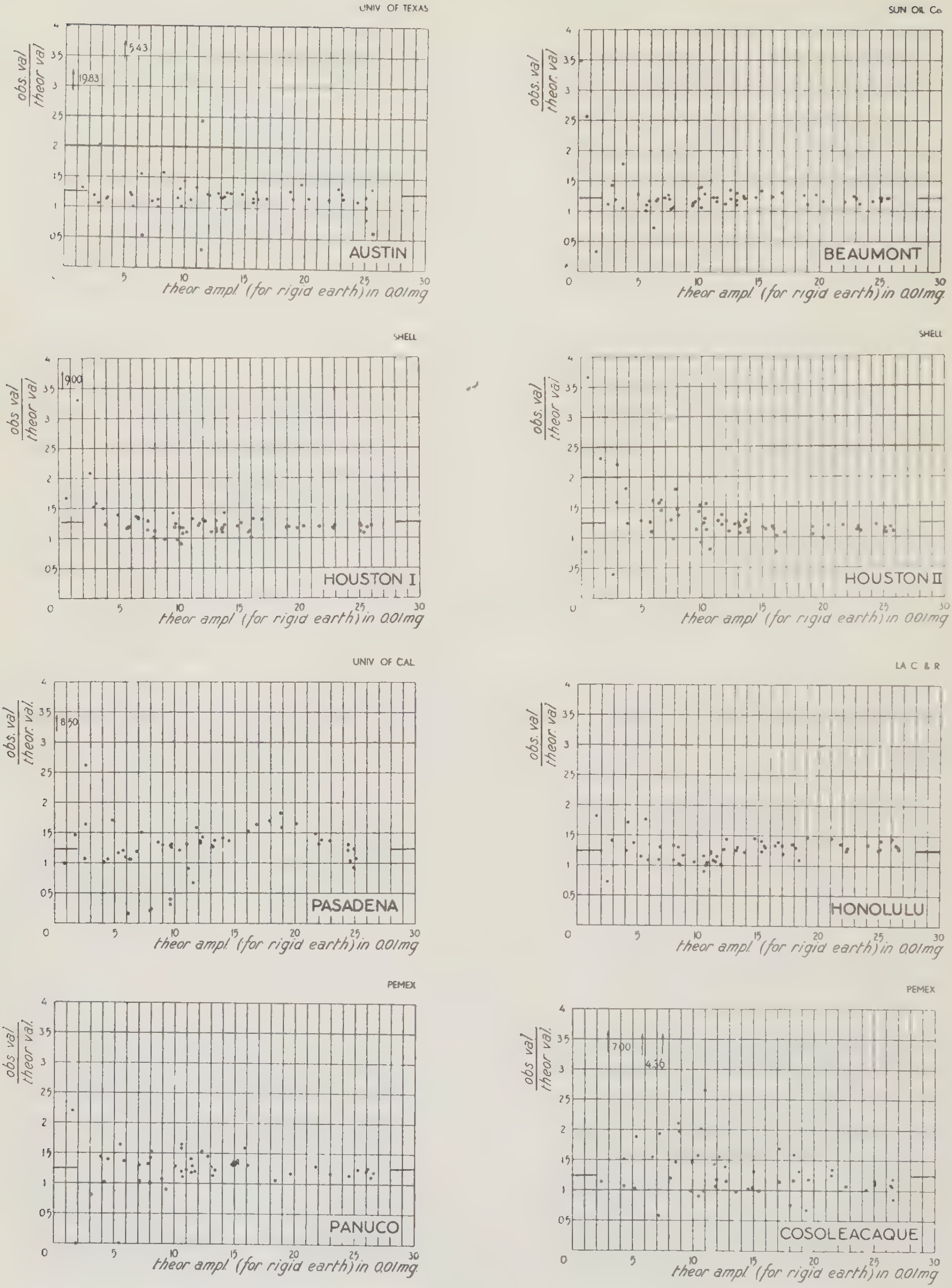
UNIV OF TEXAS
AUSTIN
19.83
5.43
SUN OIL Co
BEAUMONT
SHELL
HOUSTON I
9.00
SHELL
HOUSTON II
UNIV OF CAL
PASADENA
8.50
LA C & R
HONOLULU
PEMEX
PANUCO
PEMEX
COSOLEACAQUE
7.00
4.36
obs. val / theor. val
theor ampl. (for rigid earth) in 0.01mg
0
5
10
15
20
25
30
0.5
1
1.5
2
2.5
3
3.5
4

Fig. 2 (cont'd)

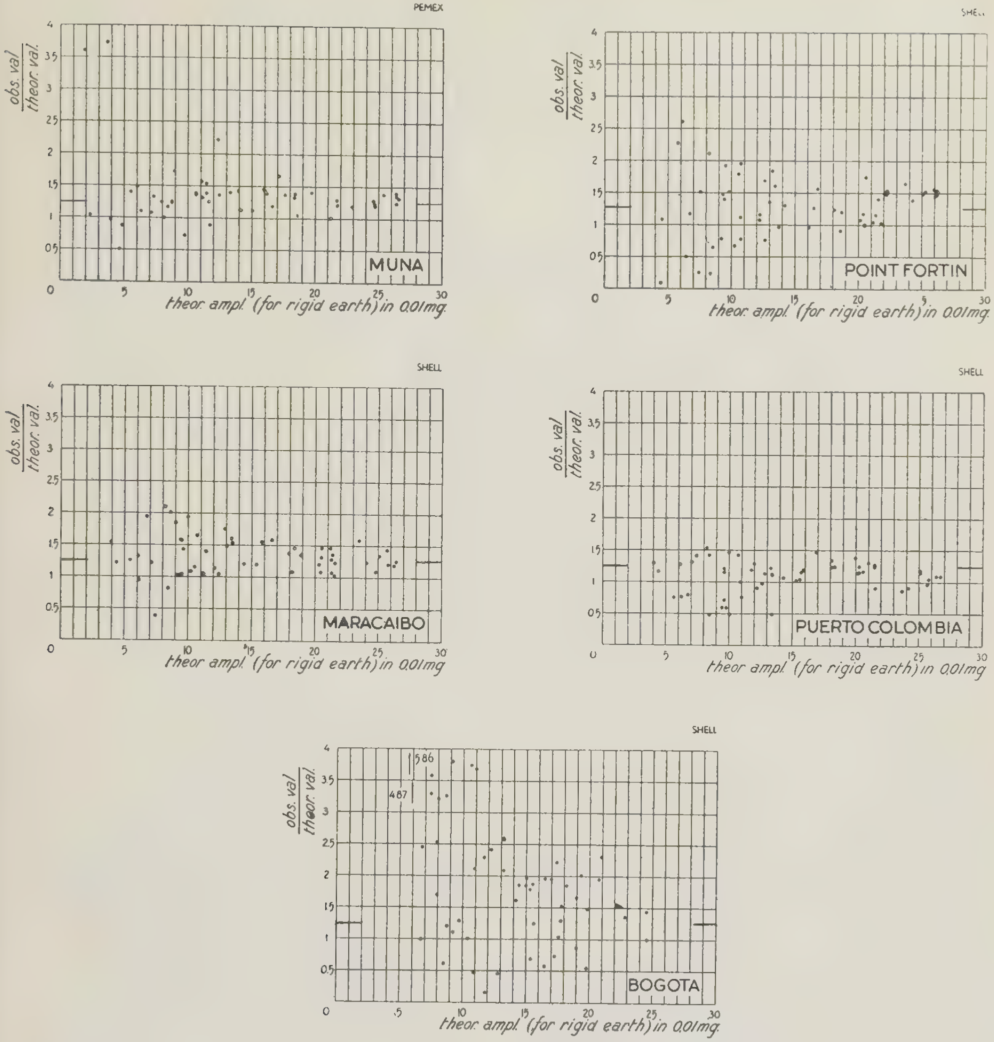

Fig. 2 (cont'd)

(continuation of p. 99)

discussions. For the other stations there is no reason known to us for discarding the measurements.

As may be read in chapters II and III a gravimeter may give erroneous readings for a number of reasons, which in most cases cannot be evaluated. It is therefore impossible to give accurate data on the errors of the separate stations, but the standard deviation (Table II) gives an idea of the accuracy. The standard deviation has been calculated by taking 1.25 times the mean deviation without regard to sign.

If we consider the stations Sorong, Edmonton and Houston, where two instruments were set up next to each other, we find the following differences in d: 0.05, 0.12 and 0.01 or 0.06, 0.04 and 0.04 for a theoretical amplitude of 0.10 mg or more. These differences are only due to the amplitudes in the observed curves as the errors in the amplitudes of the theoretical curves can be considered negligible. In these three cases the instruments were under exactly the same conditions and read by the same observers. Under different conditions and with different observers it is quite possible that larger deviations would occur between stations. As no correlation between d and the nature of the location of the stations (height, distance from the coast, inside or outside basins) could be found, it seems highly probable that an average value for d is valid for all stations in view of the accuracy of the separate stations. A line with tangent 1.24 has been drawn in the diagrams of fig. 1 to show the deviations. A station like Toronto could give rise to some doubt as to whether a value of 1.22 or 1.24 for d may not be too high. One of the uncertainties is the removal of the drift of the gravity meter. The values for Toronto in Table II are based on the removal of a smooth drift curve. Taking out only a linear drift we obtain different values. For comparison the differences are given here:

	Smooth drift	Linear drift
All ampl.	d = 1.09 st. dev. 0.19	d = 1.12 st. dev. 0.22
Ampl. ≥ 0.10 mg	d = 1.06 st. dev. 0.14	d = 1.09 st. dev. 0.19

We suppose that the values given in Table II are better because in the smooth drift curve there hardly anything remains with periods of 24 or 12 hours (see Chapter III, c). A comparison with other stations such as Edmonton I and II shows that another measurement might have given a value even higher than 1.24.

Another example of the variations of d is at Pasadena. We found for d the values 1.25 and 1.33 and on the basis of nearly the same data, which were subjected to a 15 day harmonic analysis with central day May 18, 1949 (4) was found as a weighted mean of the M_2, S_2, K_1 and O_1 components the value 1.10. The values for each of the components are, in the above order 1.19, 1.26, 0.93 and 1.14. We see that large variations already exist with nearly the same material.

A further indication that the values d are more or less randomly distributed around an average value is shown when we plot the 26 stations on one graph (figs. 3a and 3b). If we draw lines parallel to a straight line with tangent 1.25 in fig. 3a at vertical distances of 0.05 mg, count the number of points between the lines and plot these numbers against the distance (fig. 4), the result satisfies quite well a normal distribution curve. The full drawn line is a normal distribution curve with the same number of points and with the same mean and standard deviation (5). This mean is on the negative side of the line with slope 1.25. We did the same for a line with slope 1.20 and found the mean on the positive side. The slope should therefore be about midway between 1.20 and 1.25.

It may still well be that the individual stations show some systematic deviations (e.g. inexact constants) but these are then small and distributed

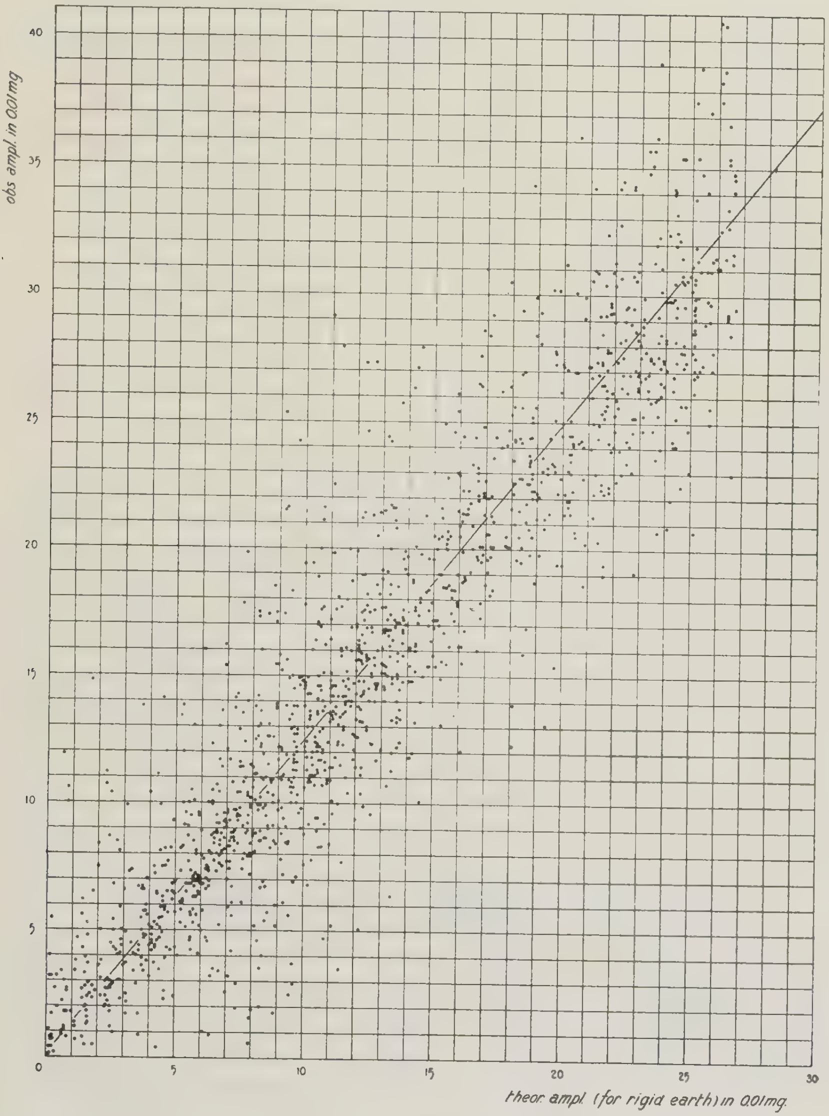

Fig. 3 a

more or less at random over the stations. It is very unlikely that all stations would show a systematic deviation in one direction only.

A comparison of a number of results obtained at different stations with the harmonic analysis for each of those stations made by the U.S.C. and G.S. and published by Hoskinson (6) is shown in Table III (Pasadena has been left out, because the measurements do not coincide). The average values d obtained from the harmonic analysis are all lower than those from the amplitudes. This seems mainly due to the low values for K_1 and O_1. We will not enter upon the subject as to how far these constituents are influenced by other constituents

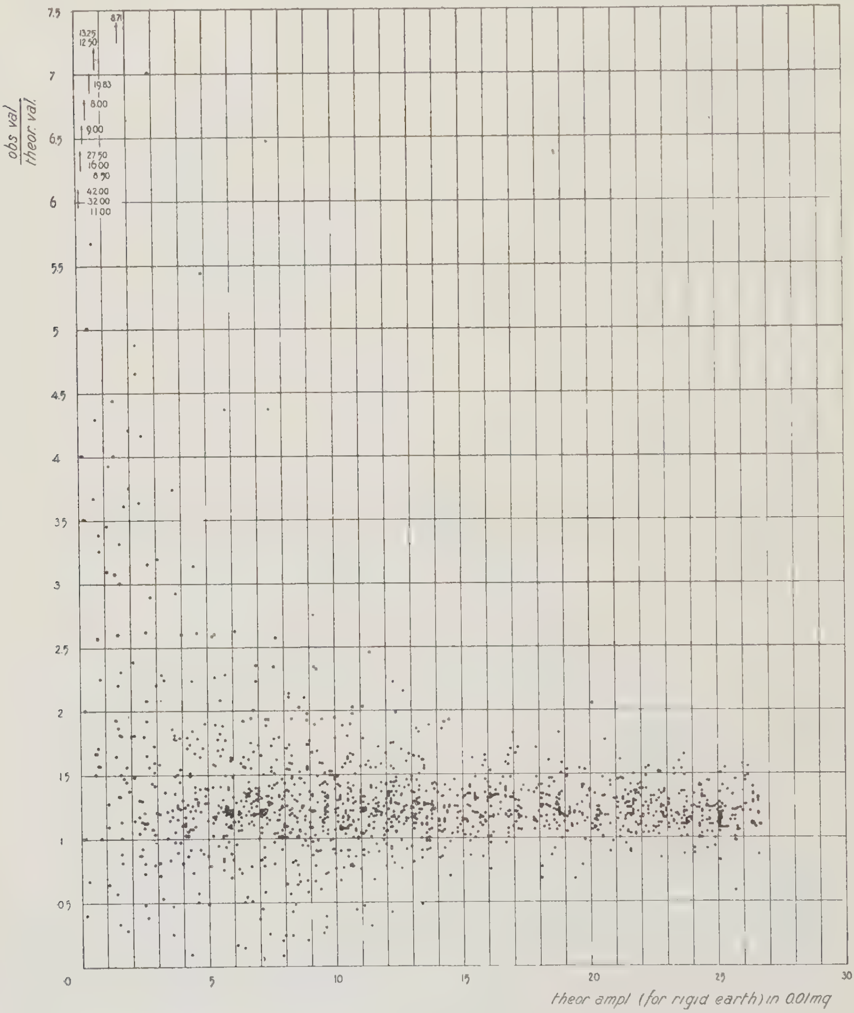

Fig. 3 b

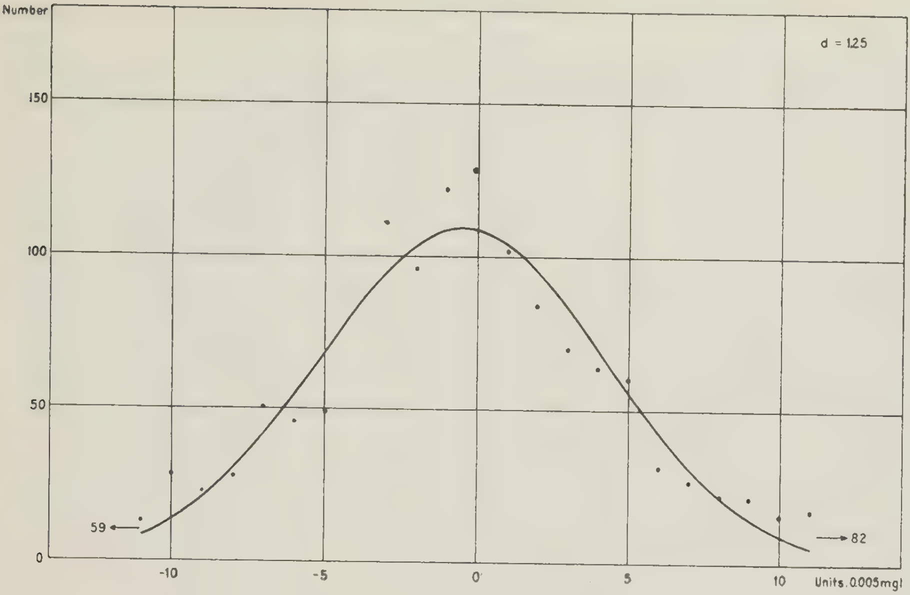

Fig. 4

of approximately the same periods, but in calculating values for d, the use of amplitudes has the definite advantage that all constituents are present.

Furthermore, the phase difference Q between the theoretical and observed curves is, within the accuracy of the measurements, zero. As pointed out previously, this should be the case if the earth behaves according to the simple theory of Love. Thus, the non-existence of a phase difference points also to the conclusion that a constant value for d is highly probable.

The most probable value of d from our observations is 1.22 and if there is a variable effect superimposed on this value, it must be very small. A big influence on the gravity effect of earth tides has often been ascribed to the gravitational action of the ocean tides and the shifting load of tidal water, but this is, taking into consideration the accuracy, not confirmed by our measurements. This effect, if present, is very small.

If we combine our value d with the best known value D ($= 1 - h + k$) of Nishimura (1), who found $D = 0.66$, we get for $h = 0.58$ and $k = 0.24$. These values are lower than the general accepted values. In a publication of Takeuchi (7) the simple theory of Love was extended and values for h and k were calculated for different earth models. Table II of his publication (page 688) gives a summary of the calculated values for h and k. The highest value for d obtained with a core rigidity of 10^7 to 10^9 dynes/sq.cm is 1.193, while D does not come below 0.67. These values are based on a surface density of 3.0. Taking a surface density of 2.7 the various constants become

TABLE III

Values of d:

Station	M_2	S_2	K_1	O_1	Average	Our values	
Toronto	1.19	1.18	1.03	1.10	1.11	1.09	1.06
Ottawa	1.31	1.41	1.15	1.24	1.25	1.29	1.21
Edmonton 1	1.04	1.36	1.12	1.14	1.13	1.22	1.16
Edmonton 2	0.97	1.46	1.05	1.30	1.14	1.10	1.10
Salt Lake City	1.27	1.06	1.37	1.04	1.22	1.39	1.30
Fort Morgan	1.20	1.00	1.11	1.15	1.13	1.16	1.16
Washington	1.27	1.06	1.16	1.15	1.19	1.23	1.19
Tulsa	1.26	1.53	1.33	1.09	1.29	1.30	1.27
Albuquerque	1.09	0.81	0.82	1.11	0.97	1.27	1.16
Austin	1.17	1.08	1.11	1.01	1.13	1.19	1.19
Beaumont	1.20	1.31	1.22	1.23	1.23	1.21	1.22
Houston 1	1.18	1.15	1.18	1.14	1.17	1.19	1.18
Houston 2	1.19	1.15	0.87	1.13	1.09	1.18	1.14
Honolulu	1.16	1.34	1.27	1.52	1.32	1.28	1.29
Panuco	11.6	1.15	1.32	1.13	1.19	1.26	1.27
Muna	1.21	1.27	1.74	1.26	1.34	1.32	1.33
Average	1.19	1.21	1.18	1.17	1.18	1.23	1.21

Model 1 $h = 0.574$ $k = 0.261$ $d = 1.183$ $D = 0.687$
Model 2 $h = 0.598$ $k = 0.256$ $d = 1.214$ $D = 0.658$
Model 3 $h = 0.587$ $k = 0.239$ $d = 1.229$ $D = 0.652$.

This shows that the earth models given by Takeuchi can be fitted to the observed values of d and D by a small change in the surface density. More accurate data are necessary before a decision can be made as to which earth model represents the behaviour of the actual earth.

V—SUMMARY AND CONCLUSIONS

Although the reading accuracy at nearly all stations lies between 0.01 and 0.02 mgl an uncertainty is introduced in correcting the measurements for jumps and drift. After a jump the drift normally has changed and may come slowly back to normal again, while a large or irregular drift cannot be determined accurately. A number of other reasons, such as e.g. temperature constancy, levelling accuracy, constant of the instruments, etc., may give rise to a deviating value of d, notwithstanding that all normal precautions have been taken. It is also clear from the graphs that two weeks is about the minimum observation time required for the determination of a reasonable value for d.

Summing up the results on the basis of the discussions and descriptions given in the foregoing chapters and in view of the accuracy of the measurements, it can be stated that:

The ratio d of the amplitudes from the curves representing the gravity effect

of a yielding and rigid earth at 26 stations is 1.22 and no phase difference exists;
if this value d contains a variable term, it is only a secondary order effect;
no correlation has been found between d and ocean tides, height of stations or location of stations within the accuracy of the measurements.

Finally one point of practical importance will be mentioned. It has been pointed out in the introduction that in modern gravity surveys the number of stations measured depends to a large extent on the returns to base stations required. These returns can be less frequent, if the gravity meter has a very small and regular drift, when a return need only be made at the end of the working day, thus saving considerable time, especially under difficult terrain conditions. In that case, however, a correction for the tidal gravity variations has to be applied because these variations cannot be interpolated linearly with sufficient accuracy over a longer period than 2 hours. With a known and constant factor it is not necessary to measure the values d and Q for different areas with a gravity meter, a time consuming and expensive procedure, but the corrections can be calculated very easily with the aid of nomograms.

VI—Acknowledgements

The writer wishes to thank the Bataafsche Petroleum Maatschappij for permission to publish the data and results of the Shell stations and for their generous attitude in the measurement of so many stations.

Many thanks are also due to the University of Toronto, the Dominion Observatory of Canada, the United Geophysical Co. of Canada, the University of Utah, the Colorado School of Mines, the United States Coast and Geodetic Survey, the Humble Oil and Refining Co., the University of Texas, the Sun Oil Co., the University of California (LA), the La Coste and Romberg Co. and the Petroleos Mexicanos for their valuable assistance in measuring one or more stations each.

I am especially indebted to Ir. A. van Weelden, who initiated this programme, for his stimulation and the interest he has taken in the preparation of this paper.

My thanks are also due to everybody who assisted in the programme or in the preparation of the paper.

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(2) P. Schureman, "Manual of Harmonic Analysis and Prediction of Tides", U.S.C. and G.S. Special Publication No 98.
(3) B. Baars, "Getijden-Veranderingen van de Zwaartekracht", Geologie en Mijnbouw 12, 81, 1950.
(4) M. S. Reford, "Tidal Variations of Gravity", Transactions Am. Geoph. Union 32, 151, 1951.
(5) L. H. C. Tippett, The Methods of Statistics, page 40.

(6) A. J. Hoskinson, "Harmonic Analysis of Gravity Observations", Transactions Am. Geoph. Union 32, 163, 1951.
(7) H. Takeuchi, "On the Earth Tide of the Compressible Earth of Variable Density and Elasticity", Transaction Am. Geoph. Union 31, 651, 1950.

Discussion

Mr. Tomascheck: In connection with the Shell programme two stations for tidal measurements were established by the Anglo-Iranian Oil Co. in the United Kingdom. They were Kirklington (53° 07′ N; 00° 59′ W) and Peebles (55° 39′ N; 3° 11′ W). Frost gravimeters have been used, one directly doubly thermostatically controlled, the other one with single control, but set up in a thermostatically controlled room.

The overall mean G* of the regressions of each set of 672 values gives as the ratio of observed to theoretical values

for Kirklington G* = 1.00 ± 0.015
for Peebles G* = 1.10 ± 0.015.

The harmonic analysis, after applying the pressure corrections and corrections for a diurnal meteorological term with an amplitude of 0.006 ± 0.001 milligals, the maximum occurring in the morning hours, gives for the ratio G of observed amplitude to theoretical

G = 1.09 ± 0.03 for the diurnal constituents at both stations.
G = 1.09 for the semidiurnal lunar term M_2 at Peebles and
G = 1.24 at Kirklington.

The difference between the values of the gravimetric ratio at Peebles and Kirklington Hall derived from the semidiurnal term can be attributed to different influences of the sea tides as observations with horizontal pendulums show. An approximate correction for this influence makes probable a value of G = about 1.15 for both stations for the lunar semidiurnal M_2 ratio.

A third station has been established later at Winsford (53° 12′ N; 2° 30′ W) with measurements taken from 16th April, 1951, to 27th. The overall mean of these measurements is G* = 1.22 ± 0.025.

Mr. Jung: How is the phase difference between theoretical and observed curves?

Mr. Baars: Within the accuracy of the measurements negligible.

Mr. van Weelden: The location of the stations was chosen purposely to have a variety of circumstances: near the coast, inland, on lowland, on high plateaux, in basins and on shields.

Mr. Germain-Jones: Has it been tried to use this correction with only a few returns to base?

Mr. Baars: Yes, in several places with very satisfactory results. The closing errors were much smaller after applying the tidal gravity correction.

LAUFZEITMESSUNGEN AN BOHRKERNEN UND GESTEINSPROBEN MIT ELEKTRONISCHEN MITTELN *

VON

HEINRICH BAULE **

ABSTRACT

Supersonic pulses are transmitted into rock samples and cylindrical drill cores of about 10 cm to about 100 cm in length by a magnetostrictive driver attached to one end. The pulses are received at any chosen distance along the core by a small crystal geophone resting on the specimen. The beginning of the supersonic pulse and the wave form of the received disturbance, together with the marks of an accurate timer by a quartz clock, are made visual and stationary on the screen of a cathode-ray oscillograph and the travel-time is measured. Thus the core is picked up at different distances and a travel-time curve is drawn from which the velocity of the waves is determined.

The method is interpreted and the measuring device described. Graphs give several travel-time curves of different rock samples, drill cores, metal rods and rods of other solid materials. The elastic moduli E of the samples are communicated, and an example is given for determining Poisson's ratio δ from longitudinal and transversal velocities on two cores of sandstone.

Im folgenden wird über einige Laufzeitmessungen an Bohrkernen und Gesteinsproben berichtet, die in der Geophysikalischen Abteilung der Westfälischen Berggewerkschaftskasse in der Zeit von Februar bis November 1952 vorgenommen worden sind.

Für Laufzeitmessungen über besonders kurze Entfernungen, insbesondere unter 1 m, versagen die photographischen Registrierverfahren. Man bedient sich für diese Zwecke mit Vorteil der hohen Zeitauflösung mittels Kathodenstrahloszillographen. Hierbei werden die notwendigen Erschütterungsimpulse als Ultraschallstösse von verschieden hoher Frequenz oder auch als Knallfunken in die Proben hineingesendet und ihre Laufzeit gemessen.

Diese sogenannten elektronischen Messverfahren gewinnen in letzter Zeit über das Laboratorium hinaus auch für den Geophysiker in der Praxis immer mehr Bedeutung, wie ein Blick in eine Auswahl des diesbezüglichen Schrifttums erkennen lässt.

So haben Hughes und Jones (1) und ebenso Hughes und Cross (2) mit Ultraschall die longitudinalen und transversalen Geschwindigkeiten elastischer

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* Presented at the Hanover Meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

** Westfälische Berggewerkschaftskasse, Bochum, Germany.

Wellen in Sedimentgesteinen bei Drücken von 0 kp/cm^2 bis 2000 kp/cm^2 und 5000 kp/cm^2 und bei Temperaturen von 25° C bis 175 ° C bzw. bis 200° C und 300° C gemessen.

Kaufmann und Roever (3) berichten über Laboratoriumsuntersuchungen und Laufzeitmessungen in einem Wachsblock mit Hilfe von Knallfunken-Impulsen.

Risnitschenko, Ivakin und Bugrov (4) haben u.a. Modellversuche zum 2-Schichtenproblem ausgeführt, wobei die Laufzeiten von Ultraschallimpulsen in Wasser mit einer eingetauchten Aluminiumplatte als 2. Schicht gemessen wurden.

Chefdeville und Dawance (5), deren Arbeit mir erst vor wenigen Wochen zu Gesicht gekommen ist, berichten schon 1950 über Laufzeitmessungen und Resonanzmessungen mit Ultraschall an Betonproben und an Bauwerken aus Beton.

Gough (6) beschreibt bereits eine Feldapparatur für elektronische Laufzeitmessungen nach dem Refraktionsverfahren für Schichttiefen bis zu 30 m und Profile bis ca 250 m Länge; die Erschütterungsimpulse werden hierbei mit einem mechanischen Hammer erzeugt.

Von Vogel (7) und von Summers und Broding (8) werden Bohrloch-Messgeräte für kontinuierliche Laufzeitmessungen mit Knallfunken (7) und mit Ultraschallimpulsen (8) über ca. 1,50 m Entfernung durch die Gesteinswand in Bohrlöchern — seismic velocity logging, continous velocity logging — beschrieben. Die ersten Ergebnisse und Erfahrungen mit dieser Methode in der Feldarbeit werden mitgeteilt.

DIE MESSMETHODE

Das Prinzip unserer Messung — Fig. 1 — besteht darin, dass wir in ein Ende des Bohrkerns 50 mal pro sec einen Ultraschallimpuls von ca. 22 kHz hineinsenden und an vielen, verschieden weit vom Sender entfernten Messpunkten am Bohrkern entlang nacheinander die Erschütterungen abtasten. Der

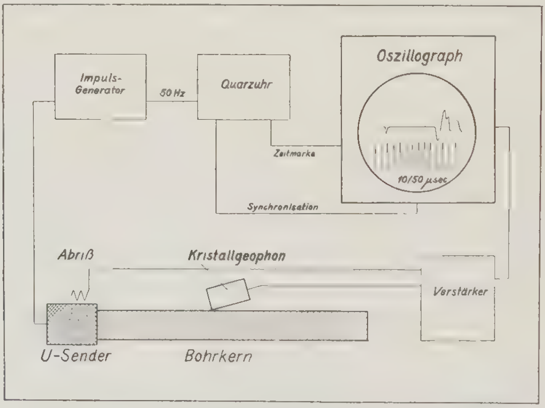

Fig. 1. Blockschaltbild zur elektronischen Laufzeitmessung an einem Bohrkern.

Sendeimpuls — Abriss — und die an dem hochabgestimmten Kristallgeophon ankommende Erschütterung werden zusammen mit einem genauen Zeitmassstab mit Hilfe elektronischer Vorrichtungen auf einem Zweistrahloszillographen als stillstehendes Bild sichtbar gemacht und die Laufzeit abgemessen. Der Zeitmarkenabstand lässt sich an der Quarzuhr wahlweise z.B. auf 10 μsec oder 50 μsec einstellen. Danach wird eine Laufzeitkurve gezeichnet, aus der sich die Geschwindigkeit ergibt.

Wir verwenden relativ langwellige Ultraschallstösse; die Wellenlänge ist gross gegenüber dem Durchmesser der Kerne und beträgt etwa 7 cm bis 27 cm bei Geschwindigkeiten zwischen 1500 m/sec bis 6000 m/sec. Es wird somit die longitudinale Schallgeschwindigkeit in einem Stab gemessen, die „Dehnungswelle" nach Bergmann (9), für welche die einfache Beziehung gilt $v = \sqrt{\frac{E}{\rho}}$, mit v = Geschwindigkeit in m/sec, ρ = Dichte in g/cm³ und E = Elastizitätsmodul in kp/cm². Die Dichte der Bohrkerne lässt sich im Laboratorium leicht bestimmen, so dass auch der E-Modul bequem zu errechnen ist.

DIE MESSAPPARATUR

In Fig. 2 ist die Messbahn gezeigt. Der magnetostriktiv angeregte Ultraschallsender aus Nickel ist im Bilde links mit einer Schraubzwinge gegen das Ende des Bohrkerns gepresst. Die Stirnseite des Kernendes braucht hierfür nicht plan geschliffen zu werden, es genügt die beim Absägen entstehende Schnittfläche. Das Geophon wird mit seiner Kante durch einen Hebelarm mit schwerem Endgewicht auf den Kern gedrückt und seine Entfernung vom Sender auf dem Metallmeterstab mit Schleppzeiger auf mindestens 1 mm genau abgelesen.

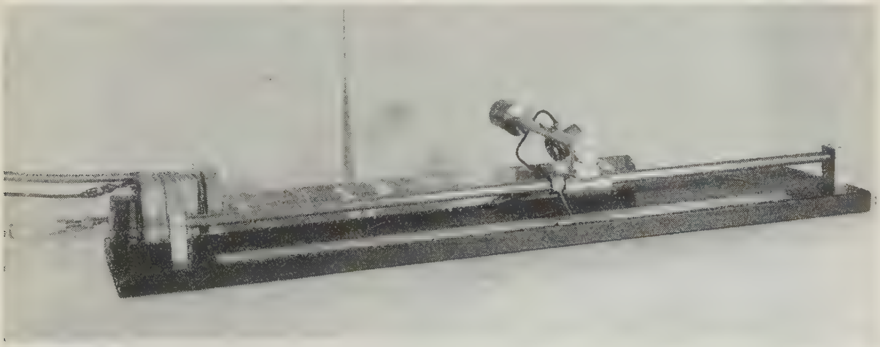

Fig. 2. Die Messbahn mit Ultraschallsender, Bohrkern und Geophon.

Die elektronischen Messgeräte sind in Fig. 3 abgebildet. Unten im Bild ist der nach unseren Wünschen gebaute Zweistrahloszillograph mit einem Bildschirm von 16 cm Durchmesser zu sehen, darüber in der Mitte rechts ein Verstärker und links das von uns gebaute wichtige Steuer- und Impulsgerät, das die Aufgabe hat, den richtigen Kurvenausschnitt als stillstehendes Bild einzuregeln. Auf diesen Geräten steht eine kostbare Klein-Quarzuhr mit einer Frequenzgenauigkeit von 10^{-6}, welche die Zeitmassstäbe und die Synchronisierungsspannungen liefert.

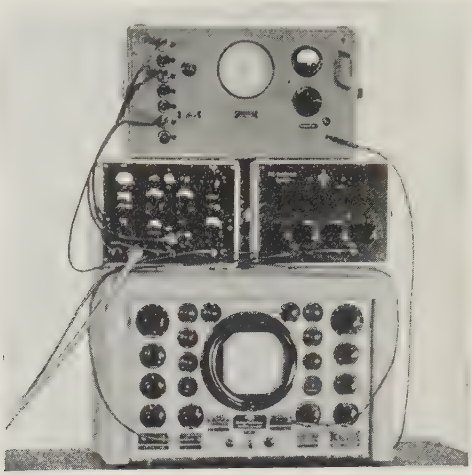

Fig. 3. Die elektronischen Messgeräte; Zweistrahloszillograph, Verstärker und Quarzuhr.

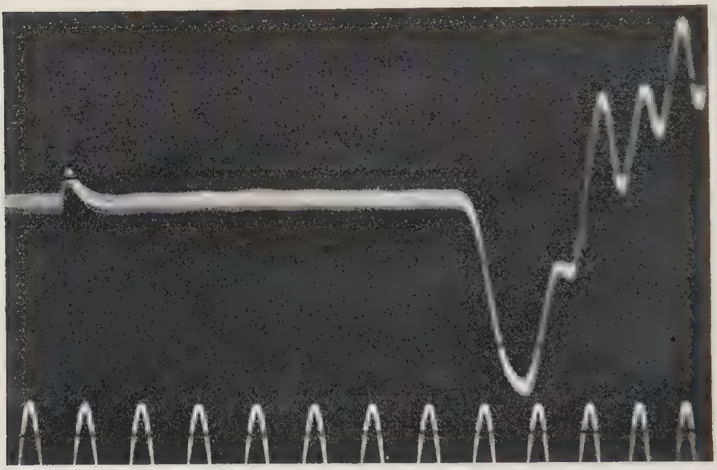

Fig. 4. Bohrkern-Oszillogramm mit Zeitmassstab von 50 μsec (20 kHz-Schwingung).

Eine Photographie des Schirmbildes mit einem groben Zeitmassstab von 50 μsec Zeitabstand — 20 000 Hz Sinusschwingung — ist in Fig. 4 wiedergegeben; das gleiche Seismogramm ist in Fig. 5 mit einem feineren Zeitmassstab von 10 μsec — 100 000 Hz Schwingung — abgebildet. Für die Ausmessung der Laufzeiten unmittelbar auf dem Bildschirm, was sehr schnell mit Hilfe einer Schieblehre zu erledigen ist, werden meist der 1. Einsatz der Erschütte-

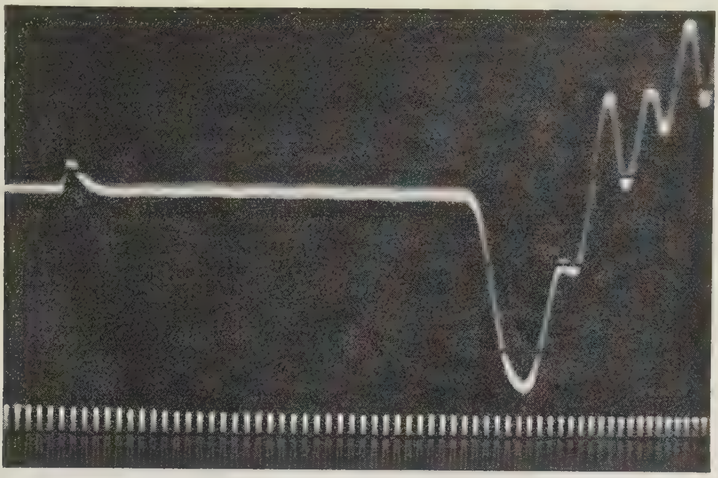

Fig. 5. Bohrkern-Oszillogramm mit Zeitmassstab von 10 μsec (100 kHz-Schwingung).

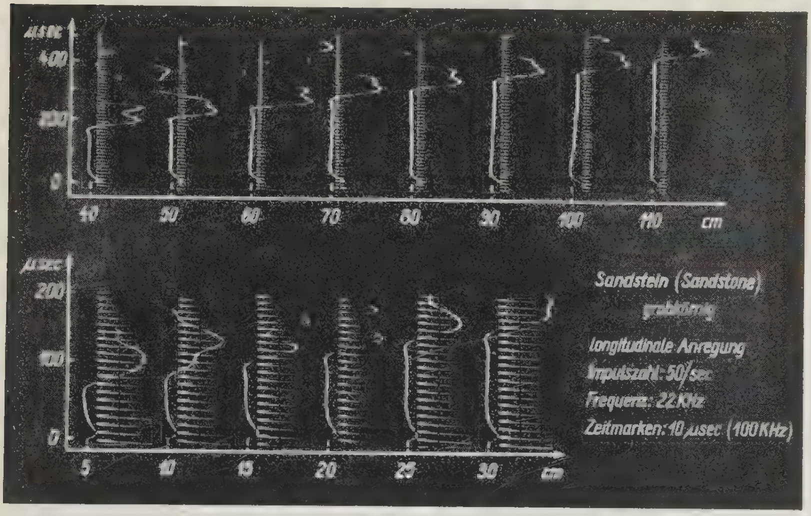

Fig. 6. Oszillogramme der Laufzeitmessung in verschiedenen Entfernungen an einem Bohrkern aus Sandstein.

rung, d.h. das Abbiegen aus der Null-Linie und der 1. Umkehrpunkt des ersten Schwingungsbogens herangezogen, gelegentlich auch andere Phasen.

In Fig. 6 sind die Laufzeit-Oszillogramme an 14 verschiedenen Messpunkten eines grobkörnigen Sandsteins von 114 cm Länge und 6,5 cm Durchmesser bei einem Zeitmassstab von 10 μsec wiedergegeben. Für die Entfernungen von 5 cm bis 30 cm ist nach je 5 cm Weg ein Bild mit hoher Zeitauflösung, d.h. hoher Kippgeschwindigkeit aufgenommen worden, wie der untere Teil der Figur zeigt. Im oberen Teil der Figur ist für die Entfernungen von 40 cm bis 112,5 cm nach je 10 cm Weg ein Bild über der Entfernungsachse eingesetzt. Die so angeordnete Oszillogrammfolge lässt anschaulich die Neigung der Laufzeitkurve im voraus erkennen. Die zu dieser Bildfolge gehörende genau gezeichnete Laufzeitkurve ist mit allen Zwischenpunkten u.a. in der Fig. 14 links abgebildet.

LAUFZEITKURVEN FÜR VERSCHIEDENE FESTE STOFFE

Natürlich wurde das Messverfahren zunächst an Stäben aus Metall verschiedener Art und an anderen festen Stoffen erprobt, von denen zuverlässige Werte der longitudinalen Geschwindigkeiten für stabförmige Proben in der Literatur vorliegen. Das Bild in Fig. 7 zeigt die von uns gemessenen Laufzeitkurven an vier Rundstäben mit folgendem Ergebnis, das mit dem aus der Literatur bekannten gut übereinstimmt:

Material	*Durchmesser in cm*	*Länge in cm*	*Geschwindigkeit in m/sec*
Stahl	5,0	102,4	5000
Messing	4,8	120,5	3250
Hartgewebe	2,0	50,0	2500
Hartgummi	1,55	80,5	1580

Aus diesen Materialien wurde ein Modellkern von 1 m Länge mit 4 verschraubten Teilstücken von je 25 cm Länge und einem Durchmesser von 2,5 cm hergestellt und dieser „Kern" hin und zurück in Abständen von je 2,5 cm ausgemessen. Fig. 8 zeigt die Laufzeitkurven, aus denen sich die Geschwindigkeiten und — an den Knickpunkten — die Längen der Einzelstücke für Stahl, Messing, Hartgewebe und Hartgummi gut herausheben, wie das zu erwarten war. Aus diesem Bild möge man einen wichtigen Vorteil unserer Messmethode erkennen, nämlich den, dass durch die punktweise Abtastung der Laufzeiten entlang der Messstrecke plötzliche Geschwindigkeitsänderungen miterfasst werden. Bei einer Laufzeitmessung, die nur zwischen Anfang und Ende eines solchen Bohrkerns ausgeführt wäre, würde man lediglich eine unsichere Aussage über die mittlere Geschwindigkeit machen können, die in unserem Beispiel des Modellkerns für Stahl und Hartgummi völlig unzutreffend wäre.

Ein ähnlicher Effekt der Geschwindigkeitsänderung wie beim Modellkern liess sich an einem 68,5 cm langen Kern aus grobkörnigem Sandstein mit Kalkspatklüften von 4,16 cm Durchmesser feststellen, der an seinem Ende in ein ca. 20 cm langes festes Stück aus mittelkörnigem Sandstein überging. Die in

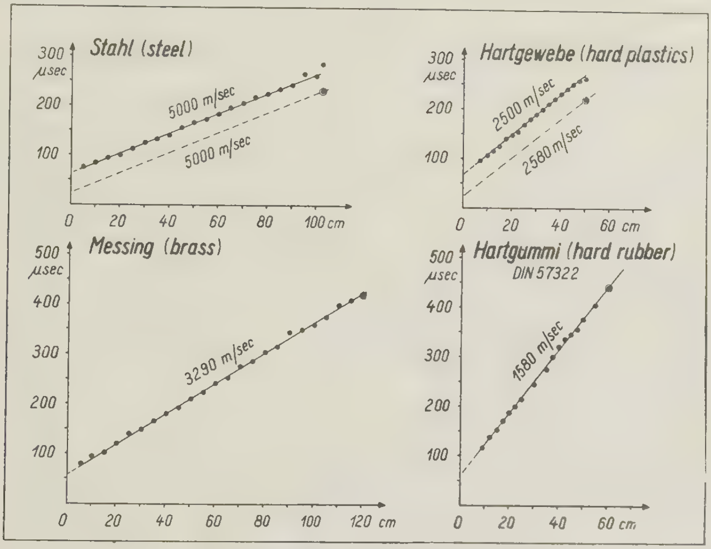

Fig. 7. Laufzeitkurven für Rundstäbe aus Stahl, Messing, Hartgewebe und Hartgummi.

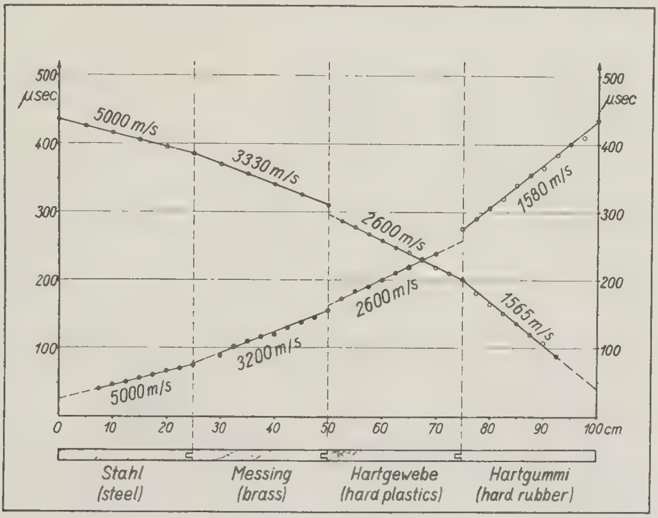

Fig. 8. Laufzeitkurven für einen 4-teiligen Modellkern aus Stahl, Messing, Hartgewebe und Hartgummi.

Fig. 9 dargestellten Laufzeitkurven ergaben für den Teil aus grobkörnigem Sandstein v = 3960 m/sec bezw. 3980 m/sec; warum bei der Rückmessung im festen Teil aus mittelkörnigem Sandstein der Geschwindigkeitswert nur 4550 m/sec statt 5000 m/sec beträgt, kann z. Zt. noch nicht befriedigend erklärt werden.

In Fig. 10 ist ein Musterbeispiel einer Laufzeitkurve für einen schlanken Bohrkern von 70 cm Länge und 2,2 cm Durchmesser abgebildet, der im Sandstein einer Zeche an der Ruhr aus dem Liegenden des Flözes Girondelle in

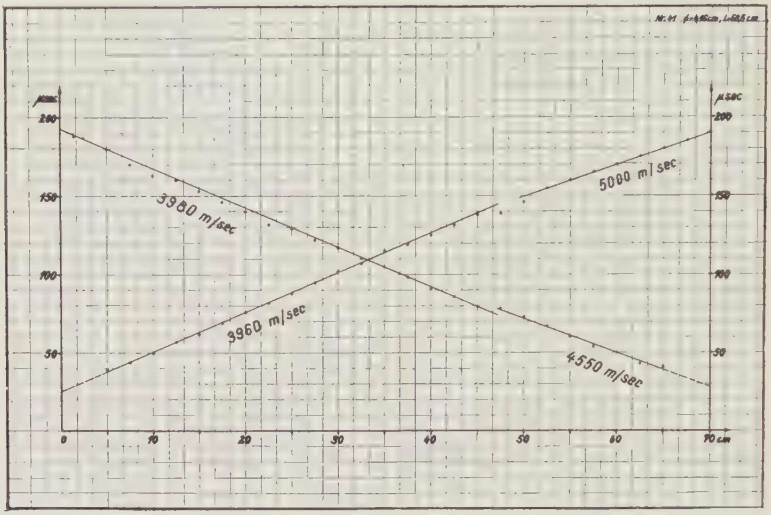

Fig. 9. Laufzeitkurven für einen Kern aus grobkörnigem, klüftigen Sandstein mit einem Endstück aus mittelkörnigem, festen Sandstein (Ruhrkarbon —750 m).

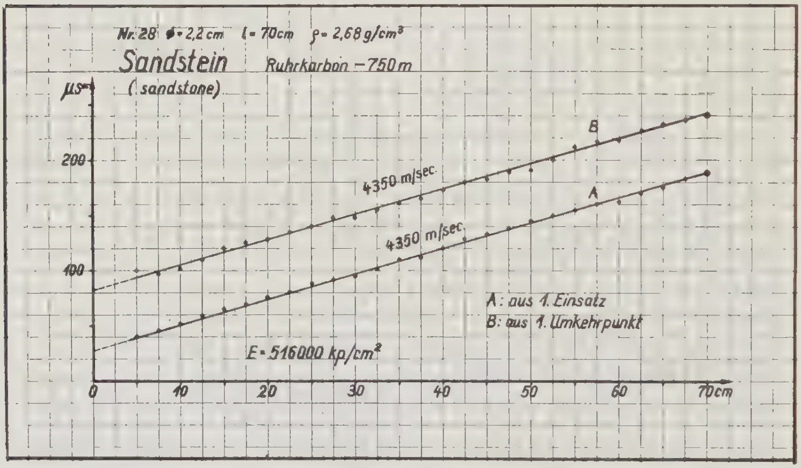

Fig. 10. Laufzeitkurven für einen Sandsteinkern aus dem Liegenden eines Kohlenflözes.

—750 m Teufe erbohrt war. Es sind sowohl die Laufzeiten für den ersten Einsatz — Kurve A — als auch den 1. Umkehrpunkt — Kurve B — eingetragen. Die Geschwindigkeit ergibt sich in beiden Fällen zu v = 4350 m/sec. Der E-Modul dieses Sandsteins, dessen Dichte mit ρ = 2,68 g/cm³ gemessen wurde, beträgt demnach E = 516 000 kp/cm². Das Bild zeigt anschaulich, dass sich

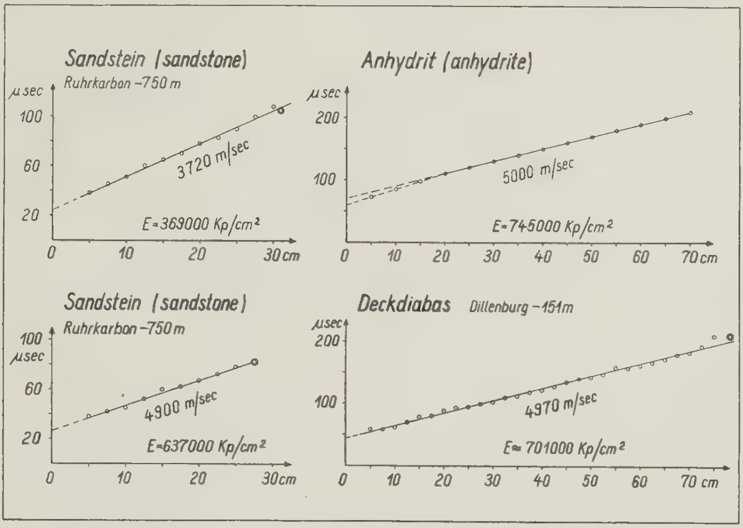

Fig. 11. Laufzeitkurven für Bohrkerne aus Sandstein, Anhydrit und Deckdiabas.

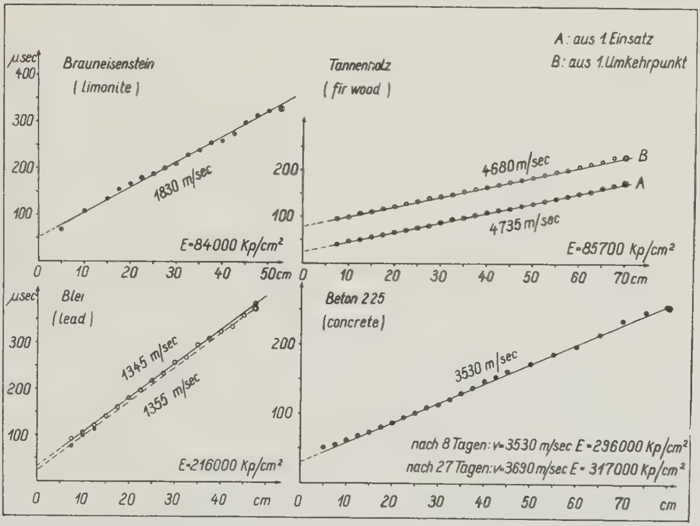

Fig. 12. Laufzeitkurven für einen Bohrkern aus Brauneisenstein, einen Rundstab aus Blei, Vierkantstäbe aus Tannenholz und Beton 225.

bei dieser durch viele Punkte belegten Laufzeitmessung die Streuung bzw. Abweichung der Messwerte von der mittleren, durchschnittlichen Geschwindigkeitsgeraden gut kontrollieren lässt.

Fig. 11 zeigt in der linken Bildhälfte, dass sehr grosse Geschwindigkeitsunterschiede in einem als geologisch gleichartig anzusehenden Sandstein vorliegen können. Die beiden Kerne stammen aus einem horizontalen Bohrloch in einem horizontal gelagerten Sandsteinpaket von 25 m Dicke in —750 m Teufe auf einer Zeche im Ruhrgebiet. Der Kern mit v = 3720 m/sec (l = 31 cm, Ø = 3,2 cm, ρ = 2,62 g/cm³) war aus 8 m Tiefe, der Kern mit v = 4900 m/sec (l = 27,6 cm, Ø 3,2 cm, ρ = 2,61 g/cm³) aus 23 m Tiefe desselben Bohrloches gezogen. Der E-Modul ändert sich bei diesen beiden, 15 m voneinander entfernt dem Gebirge entnommenen Kernen mit praktisch gleicher Dichte des Gesteins von E = 369 000 kp/cm² auf E = 637 000 kp/cm². Solche Feststellungen sind für den Bergmann bei der Erörterung von Gebirgsdruckfragen wertvoll.

Die Laufzeitkurve für den Anhydritkern (l = 73 cm, Ø = 6 cm, ρ = 2,925 g/cm³) mit v = 5000 m/sec und E = 745 000 kp/cm² zeigt eine äusserst geringe Streuung der Messwerte. Im Gegensatz dazu steht der schöne, bunte Diabaskern — siehe auch Fig. 2 — aus dem Dillenburger Erzgebiet (l = 78,3 cm, Ø = 6,2 cm, ρ = 2,79 g/cm³) mit v = 4970 m/sec und E = 701 000 kp/cm², dessen unregelmässiger Aufbau mit Kalkeinlagerungen wohl einen guten mittleren Geschwindigkeitswert von 4970 m/sec aufweist, aber eine grössere Streuung der Messwerte um die Laufzeitgerade ergibt.

In Fig. 12 streuen die Messwerte ebenfalls etwas um die mittlere Laufzeitkurve für den Bohrkern aus Brauneisenstein der Zechsteinformation (l = 52,7 cm, Ø = 9,4 cm, ρ = 2,45 g/cm³) mit v = 1830 m/sec und E = 84 000 kp/cm². In diesem Falle ist die Wellenlänge des Ultraschalles bei der geringen Geschwindigkeit und dem dicken Kern etwa von der Grösse des Kerndurchmessers und das Ergebnis daher weniger sicher, vergl. Bergmann * (9).

Neben der Laufzeitkurve für einen gegossenen Stab aus Blei (l = 47,5 cm, Ø = 2 cm, ρ = 11,4 g/cm³) mit v = 1345 m/sec und E = 216 000 kp/cm² ist besonders interessant die unerwartet hohe Geschwindigkeit für den □ = Stab aus Tannenholz (l = 69,8 cm, □ = 3,1 cm × 3,3 cm, ρ = 0,375 g/cm³) mit v = 4735 m/sec und E = 85 700 kp/cm². Diese hohe Geschwindigkeit wurde parallel zur Faser gemessen und zwar auch, wenn der Stab nach mehrtägiger Lagerung in Wasser etwa 35 g Wasser aufgenommen hatte und bei der Messung noch feucht war.

Das in Luft getrocknete Betonprisma (l = 80 cm, □ = 6 cm, ρ = 2,33 g/cm³) zeigte in grundsätzlicher Übereinstimmung mit den Ergebnissen von Dawance (5) eine Zunahme der Geschwindigkeit von v = 3530 m/sec und des E-Moduls von E = 296 000 kp/cm² bei einem Alter des Betons von 8 Tagen auf eine Geschwindigkeit von v = 3690 m/sec und auf einen E-Modul von

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* a.a.O. S. 456/457.

$E = 317\,000$ kp/cm² bei einem Alter von 27 Tagen. Diese Tatsache dürfte u.a. als ein Kriterium für die Erhärtung des Betons wichtig sein.

In Fig. 13 sind Versuchsmessungen an grossen und kleinen, unregelmässigen nicht-stabförmigen Gesteinsproben dargestellt. In diesen vier Beispielen ist allerdings die Wellenlänge des Ultraschalles relativ klein gegenüber den Abmessungen der Proben, jedoch noch so gross, dass genügend Energie selbst

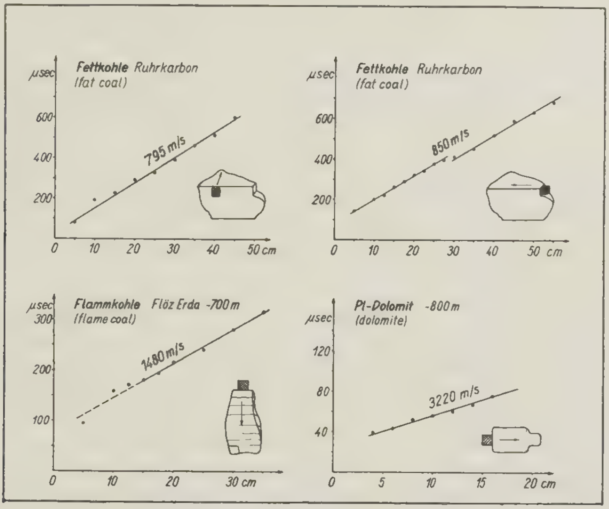

Fig. 13. Laufzeitkurven für Gesteinsproben aus Fettkohle, Flammkohle und Platten-Dolomit.

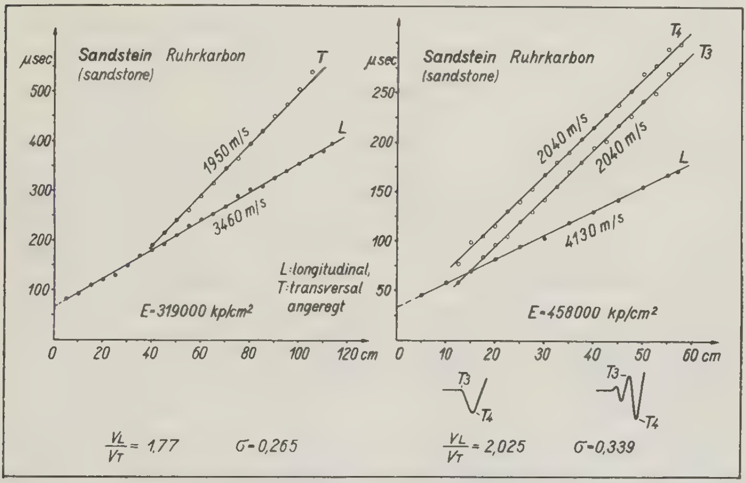

Fig. 14. Laufzeitkurven für 2 Bohrkerne aus verschiedenartigem Sandstein bei longitudinaler und transversaler Anregung.

durch die Klüfte z.B. in den Kohleblöcken hindurchdringt. Für einen grossen Block aus Fettkohle mit einem Volumen von ca. 0,5 m^3, der seit vielen Jahren im Laboratorium steht, ergeben sich die im Bilde oben links und rechts gezeigten Laufzeitkurven mit den niedrigen Geschwindigkeiten $v = 795$ m/sec und 850 m/sec in zwei zueinander senkrechten Richtungen.

In einem frischen Flammkohlen-Block (15 cm × 15 cm × 36,5 cm) aus —700 m Teufe, der 24 Stunden nach seiner Entnahme aus dem Flöz Erda in lotrechter, d.h. bankrechter Richtung gemessen wurde, betrug die Geschwindigkeit rd. 1480 m/sec; vergl. Fig. 13 links unten.

Aus der im Bilde unten rechts für ein Kernbruchstück aus Platten-Dolomit ($l = 21$ cm, $\varnothing = 6 - 12{,}5$ cm) gezeigten Laufzeitkurve ermittelt man die Geschwindigkeit $v = 3220$ m/sec.

Wir haben in unsere Bohrkerne nicht nur Ultraschallstösse in longitudinaler Richtung gesendet, sondern auch versucht, die Kerne transversal anzuregen. Die ersten Versuchsergebnisse an zwei Kernen aus verschiedenartigem Sandstein sind in Fig. 14 dargestellt. Links im Bilde ist für den grobkörnigen Sandstein ($l = 114$ cm, $\varnothing = 6{,}5$ cm, $\rho = 2{,}61$ g/cm^3) die Laufzeitkurve L mit der Longitudinalgeschwindigkeit $v_L = 3460$ m/sec und die Kurve T mit der Transversalgeschwindigkeit $v_T = 1950$ m/sec gezeigt. Der E-Modul berechnet sich zu $E = 319\,000$ kp/cm^2, das Geschwindigkeitsverhältnis $v_L/v_T = 1{,}77$ und die Poissonsche Konstante $\delta = 0{,}265$.

Aus den im Bilde rechts dargestellten Laufzeitkurven ergibt sich für den zweiten Kern aus Sandstein ($l = 58$ cm, $\varnothing = 5{,}2$ cm, $\rho = 2{,}63$ g/cm^3) $v_L = 4130$ m/sec, $v_T = 2040$ m/sec, $E = 458\,000$ kp/cm^2 und das Geschwindigkeitsverhältnis $v_L/v_T = 2{,}025$ und damit $\delta = 0{,}339$. Für die Kurven T_3 und T_4 sind bei transversaler Anregung die Laufzeiten des ersten Einsatzes T_3 und des ersten Umkehrpunktes T_4 der Erschütterungswelle gemessen. Vor diese setzen sich mit wachsender Entfernung am Kern entlang allmählich die Einsätze solcher Wellen, deren Geschwindigkeit der Longitudinalgeschwindigkeit zustrebt. Ein Vergleich dieser Messergebnisse mit anderen Messverfahren, z.B. dem Schlierenverfahren von E. Müller — Göttingen, ist vorgesehen.

In letzter Zeit haben wir ausserdem erfolgreiche Versuche mit unserer Messapparatur aufgenommen, bei denen die Kerne zu erzwungenen stehenden Schwingungen angeregt wurden. Dabei werden die Geschwindigkeiten aus den Abständen der Maxima und Minima der Amplituden berechnet, die sich im $\lambda/2$-Abstande ausbilden.

Eine praktische Bedeutung haben die in diesem Bericht geschilderten Laufzeit- und Geschwindigkeitsmessungen für die Feld- und Untertageseismik, für Gebirgsdruckfragen im Untertagebergbau und für die Beton- und Bauindustrie. Augenblicklich werden von uns die laufend anfallenden Kerne aus einer grossen Aufschlussbohrung in das Deck- und Karbongebirge im NW-Ruhrkarbon mit der elektronischen Apparatur ausgemessen.

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DISCUSSION

Mr. LINSSER: Aus einem Vortrag im Frühjahr 1952 in London ergab sich, dass die Poisson'sche Zahl von der Frequenz abhängig ist. Sind bei Ihren Versuchen die Wellengeschwindigkeiten von der Frequenz abhängig?

Mr. BAULE: Die Abhängigkeit der Poisson'schen Konstante von der Wellenlänge ist nicht eindeutig festgestellt. Einige Autoren sind nach ihren Versuchen der Auffassung, dass sich auch bei hohen Frequenzen ähnliche Werte ergeben wie bei niedrigen. Wir haben bei unseren Versuchen grundsätzlich nur niedrige Frequenzen benutzt, also Wellenlängen, die verhältnismässig gross gegenüber dem Stabdurchmesser sind, und haben nicht den grössten Wert auf die Bestimmung der Poisson'schen Konstante gelegt.

Mr. TUCHEL: Haben die Sandsteine mit Geschwindigkeiten von 3600 m/sec und 4900 m/sec ähnliches Aussehen und sind diese bezüglich Porosität, Gefüge, Bindemittel untersucht?

Mr. BAULE: Diese Sandsteine haben durchweg äusserlich dasselbe Aussehen. Sie werden zurzeit auf ihre gefügekundliche Struktur und petrographisch untersucht. Bei Laufzeitmessungen im festen Sandstein des Ruhrkarbons unter Tage stellten wir über ein Profil von 100 m Länge eine Geschwindigkeit von 4200 m/sec fest; veröffentlicht im Journal of Geophysical Research, June 1951. An einer anderen Stelle im Ruhrgebiet wurde von mehreren Messtrupps für die 200 m dicke Sandsteinlage im Karbon zwischen —700 m und —900 m Teufe eine Geschwindigkeit von 4100 m/sec in lotrechter Richtung gemessen.

Mr. TUCHEL: Eine seismische Bohrlochversenkmessung ergab in grösserer Tiefe für das Karbon (Sandsteine) die Geschwindigkeit von etwa 4300 m/sec.

Mr. BAULE: Ich glaube, eine Erklärung für die grossen Geschwindigkeitsunterschiede bei Sandstein kann man nur auf dem Wege über die gefügekundliche Untersuchung bekommen. Es sei betont, dass man von den an Bohrkernen gemessenen Geschwindigkeiten nicht ohne weiteres auf die in der Reflexionsseismik zu ermittelnden Geschwindigkeiten schliessen darf, bei denen es sich doch wohl um mittlere Geschwindigkeiten über grössere Entfernungen handelt.

Mr. LINSSER: Sie haben Wellen gemessen mit langsamen Geschwindigkeiten und vermuten, dass es transversale sind. Es besteht natürlich die Gefahr, dass es sich hier um Oberflächenwellen handelt, weil Sie an der Oberfläche messen. Bei einer Versuchsmessung mit dem Stab in Wasser müsste die Oberflächenwelle eine andere Geschwindigkeit bekommen als an der Luft, die transversale müsste gleich bleiben.

Mr. BAULE: Man braucht nicht im Wasser zu messen, sondern kann die in Frankreich als Transparenzmessung bezeichnete einfache Methode anwenden. Man misst dabei die Laufzeit durch die Kernmitte; das haben wir getan und auch dieser Wert fällt in die Laufzeitkurve.

Mr. RELLENSMANN: Ist die Apparatur im Bergbau zu verwenden?

Mr. BAULE: Die Apparatur ist für Laborzwecke bestimmt und nicht schlagwettersicher. Sie lässt sich aber als tragbare Apparatur herstellen; der Ausführung mit Schlagwetterschutz stehen grosse technische Schwierigkeiten im Wege.

Die an einem 12 cm langen Tuffkern vom Vesuv bei Neapel ermittelte Geschwindigkeit von 2500 m/sec — 2900 m/sec wurde in gleicher Grösse später bei Refraktionsmessungen in Italien durch Dr. von Helms gemessen.

POSSIBILITIES OF CONSTRUCTING TRUE RAY PATHS IN REFLECTION SEISMIC INTERPRETATION*

BY

H. DÜRBAUM **

ABSTRACT

Investigations into reflection seismic on the salt structure of Heide raised the following questions:

1) How can the different directions of trend of a series of layers be established?

2) How are the contour maps of reflecting horizons to be constructed if there is no general trend of the layers?

To answer these questions, the case of the subsoil consisting of a series of layers with plane reflecting beds and constant layer-velocities is treated strictly. The strike lines of the reflecting planes may be at any angle whatever. However, formulas for constructing contour maps of the reflecting planes have been derived. With these formulas, the problem quoted under 1) has also been solved.

The construction of contour maps is given.

For special cases, formulas are obtained which have already been proved by others.

I—PROBLEMS DISCUSSED HERE, AND STATEMENTS FOR THEIR SOLUTION

Investigations into reflection seismics on the salt structure of Heide by Rolf Bading (Prakla, Hanover) have yielded observations resembling those by Theodor Krey one year ago in the southern part of this structure (1). Reflections had been observed there which must, for several reasons, have passed the interior of the salt dome, and, at least partially, could be interpreted as such on the middle Zechstein, which formation appears here below the lower new red sandstone in an overturned structure. Through Bading's investigations there was added a further remarkable argument to Krey's arguments for the reflections coming out of the interior of the salt and not being multiple reflections on a horizon lying on top of the salt: the suggestion that the horizon from which the observed reflections have come has a rather different direction of trend from the country rock—a suggestion based on the observation that the isochronic lines (i.e. lines of constant acoustic distance from a given layer) of the corresponding reflecting beds formed an angle of 30°.

These observations have given rise to the following questions:

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** Amt für Bodenforschung, Hanover.

1) How can the different directions of trend of a series of layers be established? Do the isochronic lines give the direction of trend of the corresponding layer, or at least, do they indicate different striking?

2) How are the contour maps of reflecting horizons to be constructed if there is no general trend of the layers? For it is immediately apparent that, in the case of essentially different striking of the layers, a construction according to the usual procedure, based on the assumption that there is a general trend, and also a construction "by components", is not possible.

To answer these questions, the case of the subsoil consisting of a series of layers with plane reflecting beds and constant layer-velocities is treated strictly. The strike lines of the reflecting planes may be at any angle whatever. However, fairly clear formulas for constructing contour maps of the reflecting planes can be derived. From these formulas, the questions quoted under 1) are also answered. The special investigations will soon be reported by R. Bading and H. Dürbaum, after the observations have been based on further results of measurement. It may be mentioned only that the investigations so far have led to results which correspond very well to all facts hitherto known with reference to the structure quoted above.

The formulas and suggestions published in numerous papers for reflection seismic interpretation do not differ in so far as they yield reflection elements which are more or less inaccurate. Here are some reasons for this: 1) Each of these methods of construction will produce an exact result only if the assumptions on which they are based are fulfilled, and of course such assumptions may never agree exactly with the actual geological conditions. 2) The actual conditions are always known only to a fairly approximate degree. 3) Practice requires easy and easily applicable methods of construction, and such methods may not always be found under general conditions. Considerations of reflection seismic interpretation will always suffer in that they must lead to easy results, and in that too great an accuracy is senseless, because our knowledge of the distribution of velocity in the subsoil is rather incomplete. However, with such considerations, one should not be led to commit mistakes by disregarding essential refraction effects and effects caused by the essentially different strike of the reflecting planes, etc.—mistakes which may become fairly important, particularly at great depths. Thus the formulas derived in what follows are not so easy and brief as those applied in the usual reflection seismic interpretation work; they, or formulas like them, should be applied in cases where complicated structures are present.

The main idea of our construction is 1) to draw the isochronic lines by interpolation of the zero time measured at as many shotpoints as possible and to compute the strike lines and inclination of the layers successively from the isochronic maps; and 2) to gain from these values the angles and lengths necessary for constructing the vertical projection on the surface of rays normally reflected on the plane to be constructed, and for obtaining the corresponding depths. Strike lines and inclinations may be determined by equations obtained by applying a general relation for the time gradient, i.e. the differential quotient of the time for the normally reflected ray with respect to the distance of the shotpoints. Sp 1 and Sp 2 being two shotpoints, and $\vec{q}$ the vector which points from Sp 1 to Sp 2, t_{n1} or t_{n2} measured for the n-th reflection at the first or second shotpoint respectively, the time gradient is:

$$\frac{dT}{dy} = \frac{t_{n2} - t_{n1}}{|\vec{q}|},$$

because in the case of the reflecting horizons being plane surfaces it is the same as any quotient of differences taken in the direction considered. By specializing the investigations, this time without considering any different cases, formulas are obtained which have been proved (2), in the case of the layers having the same direction of trend. In that paper there was given a simple relation for the angle of dip of the ray normally reflected at the n-th interface. For the same angle, G. Tuchel has suggested a formula from his practical knowledge (3), and which may be proved by using the considerations noted here.

The foregoing explanations indicate how to proceed in the following. We shall now begin summarizing the notation used, in order to have an uninterrupted train of ideas.

II—Notation

The normal vector of the i-th interface is called $\vec{p}_i$, its inclination γ_i. The components of $\vec{p}_i$ in the right hand co-ordinate system defined by the vertical line and the direction of dip F_1 (= direction of the largest inclination) of the first reflecting horizon will be

$$\sin \gamma_i \cos \delta_{1i}, \ \sin \gamma_i \sin \delta_{1i}, \ \cos \gamma_i.$$

In this definition $\delta_{\sigma\tau}$ is the angle between the direction of dip of the σ^{th} and of the τ^{th} layer in an anti-clockwise direction (Fig. 1). As for the first interface being horizontal, the direction of dip F_1 becomes undefinable; we define it as equal to the direction of dip of the first interface being not horizontal. With regard to the other δ_{1i}, we need not make any particular assumptions, as in all the equations under consideration their angular functions are always multiplied by the sine of γ_i.

The connecting line of the two shotpoints Sp_1 and Sp_2 is given by the vector $\vec{q}$, including the angle δ_i with the direction of dip of the i-th boundary plane. As may be seen from Fig. 1 there is the relation

$$\delta_i = \delta_1 - \delta_{1i}.$$

$\vec{q}_{\rho}^{\,(n)}$ denotes the connecting line of the points at which the normal rays of the n-th layer pierce through the ρ^{th} boundary. In the next section we shall obtain an expression for $\vec{q}_{\rho}^{\,(n)}$ in $\vec{q}$ and vectors given by the course of the normal ray up to the n-th reflecting bed.

The course of the normal ray in the μ-th layer (Fig. 2) may be given by a vector $\vec{r}^{(n)}_{\mu}$ which is determined by the conditions that its length should be $\frac{v_{\mu+1}}{v_{\mu}}$ and that it should include an acute angle with the normal vector $\vec{p}_{\mu}$, it being understood that in the case of n layers $v_{n+1} = v_n$, and consequently $\vec{r}^{(n)}_{n} = \vec{p}_n$.

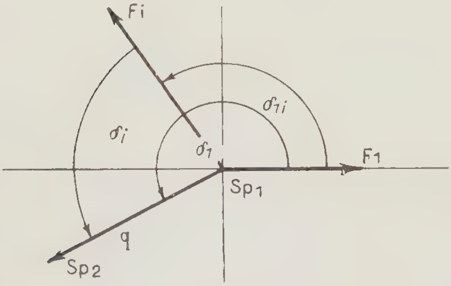

Fig. 1.

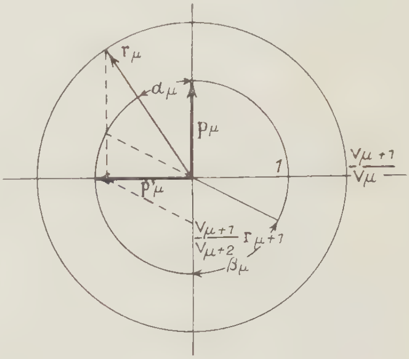
r_μ
α_μ
p_μ
1
$\frac{v_{\mu+1}}{v_\mu}$
p'_μ
$\frac{v_{\mu+1}}{v_{\mu+2}} r_{\mu+1}$
β_μ

Fig. 2.

From Fig. 2, which shows the conditions at the μ-th interface, the following relation is found:

$$\vec{r}^{(n)}_{\mu} = \frac{v_{\mu+1}}{v_{\mu}} (\cos \alpha_\mu \, . \, \vec{p}_\mu + \sin \alpha_\mu \, . \, \vec{p}\,'_{\mu})$$

$$\sin \beta_\mu \, . \, \vec{p}\,'_{\mu} = - \cos \beta_\mu \, . \, \vec{p}_\mu + \frac{v_{\mu+1}}{v_{\mu+2}} \vec{r}^{(n)}_{\mu+1} ,$$

consequently

$$\frac{v_\mu}{v_{\mu+1}} \vec{r}^{(n)}_{\mu} = (\cos \alpha_\mu - \frac{v_\mu}{v_{\mu+1}} \cos \beta_\mu) \, . \, \vec{p}_\mu + \frac{v_\mu}{v_{\mu+2}} \vec{r}^{(n)}_{\mu+1} \; (\mu = 1, \ldots, n-1).$$

Using the following abbreviation:

$$\cos \alpha_\mu - \frac{v_\mu}{v_{\mu+1}} \cos \beta_\mu =_{\text{def}} D^{(n)}_{\mu}, \; D^{(n)}_{n} = 1$$

we get

$$\frac{v_\mu}{v_{\mu+1}} \vec{r}^{(n)}_{\mu} = D^{(n)}_{\mu} \, . \, \vec{p}_\mu + \frac{v_\mu}{v_{\mu+1}} \, . \, \frac{v_{\mu+1}}{v_{\mu+2}} \vec{r}^{(n)}_{\mu+1} ,$$

and by repeatedly using this relation, it follows that

$$\vec{r}^{(n)}_{\mu} = v_{\mu+1} \cdot \sum_{\lambda=\mu}^{n} \frac{D^{(n)}_{\lambda} \vec{p}_\lambda}{v_\lambda} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

The angle of dip of that part of the normally reflected ray which belongs to the μ-th layer is called $\zeta^{(n)}_{\mu}$; $\eta^{(n)}_{\mu}$ is the angle between the direction of dip of the first reflecting horizon and $\vec{r}_\mu^{(n)}$ vertically projected on the surface. If $v_{\mu 1}^{(n)}$ is the first, and $v_{\mu 3}^{(n)}$ the third component of $\vec{r}_\mu^{(n)}$, the following relation is correct:

$$\cos \zeta_\mu^{(n)} = \frac{v_{\mu 3}^{(n)}}{|\vec{r}_\mu|} \qquad \cos \eta_\mu^{(n)} = \frac{v_{\mu 1}^{(n)}}{|\vec{r}_\mu| \sin \zeta_\mu^{(n)}}$$

or by using relation (1)

$$\cos \zeta_\mu^{(n)} = v_\mu \sum_{\lambda=\mu}^{n} \frac{D_\lambda^{(n)} \cos \gamma_\lambda}{v_\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\sin \zeta_\mu^{(n)} \cos \eta_\mu^{(n)} = v_\mu \sum_{\lambda=\mu}^{n} \frac{D_\lambda^{(n)} \sin \gamma_\lambda \cos \delta_{1\lambda}}{v_\lambda} \quad . \quad . \quad . \quad (2').$$

Finally, in order to put it more clearly, in the next section the following abbreviations are introduced (in this section we do not write the index (n) above):

$$a_{\mu\lambda} =_{\mathrm{Df}} \frac{\vec{r}_\mu \vec{p}_\lambda}{\vec{r}_\lambda \vec{p}_\lambda} \qquad A_\lambda =_{\mathrm{Df}} \frac{\vec{q} \cdot \vec{p}_\lambda}{\vec{r}_\lambda \vec{p}_\lambda} .$$

III—A FORMULA FOR THE TIME GRADIENT OF THE N-TH REFLECTING HORIZON

The conception of "time gradient" as the local differential quotient of the acoustic distances has been explained in the introduction. Now, we shall derive an equation showing the dependence of the time gradient on the direction, which is fundamental in the following. For this purpose we shall first find an expression for $\vec{q}_\rho$ in $\vec{q}$ and $\vec{r}_\lambda$ (Fig. 3).

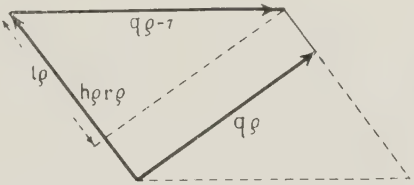

Fig. 3.

Firstly, the vector $\vec{q}_\rho$ belongs to the ρ^{th} "ray-plane", set up by $\vec{r}_\rho$ and $\vec{q}_{\rho-1}$

$$\vec{z} = -\sum_{\lambda=1}^{\rho-1} h_\lambda \vec{r}_\lambda + \tau \vec{r}_\rho + \sigma \vec{q}_{\rho-1} ,$$

and secondly it belongs to the ρ^{th} reflecting plane

$$\vec{z} = -\sum_{\lambda=1}^{\rho} h_\lambda \vec{r}_\lambda + \varkappa \vec{e}_1^{(\rho)} + \iota \vec{e}_2^{(\rho)}$$

$$\vec{e}_1^{(\rho)} \vec{p}_\rho = 0 \qquad \vec{e}_2^{(\rho)} \vec{p}_\rho = 0.$$

The intersecting line of these two planes is given by

$$\vec{z} = -\sum_{\lambda=1} h_\lambda \vec{r}_\lambda + \sigma\left(\vec{q}_{\rho-1} - \frac{\vec{q}_{\rho-1}\vec{p}_\rho}{\vec{r}_\rho \vec{p}_\rho}\vec{r}_\rho\right).$$

It is immediately evident from Figure 3 that for $\sigma = 1$ $\vec{z}$ is the local vector of the terminal point of $\vec{q}_\rho$, and consequently

$$\vec{q}_\rho = \vec{q}_{\rho\quad 1} - \frac{\vec{q}_{\rho-1}\vec{p}_\rho}{\vec{r}_\rho \vec{p}_\rho}\vec{r}_\rho .$$

Applying this relation to $\vec{q}_{\rho-1}$etc., we are able to eliminate $\vec{q}_\mu$ from it. Then we have

$$\vec{q}_1 = \vec{q} - A_1 \vec{r}_1$$

$$\vec{q}_2 = \vec{q} - A_1 \vec{r}_1 - A_2 \vec{r}_2 + A_1 a_{12} \vec{r}_2$$

$$\vec{q}_3 = \vec{q} - \sum_{\lambda=1}^{3} A_\lambda \vec{r}_\lambda + (A_1 a_{12} \vec{r}_2 + A_1 a_{13} \vec{r}_3 + A_2 a_{23} \vec{r}_3) - A_1 a_{12} a_{23} \vec{r}_3 ,$$

and finally

$$\vec{q}_\rho = \vec{q} + \sum_{\tau=1}^{\rho} (-1)^\tau \sum_{\mu_1 < .. < \mu_\tau} A_{\mu 1}\, a_{\mu 1\, \mu 2} \ldots . a_{\mu_{\tau-1} \mu_\tau} \vec{r}_{\mu_\tau} \quad . \quad . \quad . \quad (3)$$

In addition, from the Fig. above we get the following equation for the difference l_ρ of the paths which are taken by the first and the second normal ray in the ρ-th layer:

$$l_\rho = -\frac{\vec{q}_{\rho-1}\vec{p}_\rho}{\vec{r}_\rho \vec{p}_\rho} | \vec{r}_\rho \quad .$$

Now

$$\frac{t_{n2} - t_{n1}}{2} = -\sum_{\rho=1}^{n} \frac{l_\rho}{v_\rho} = \sum_{\rho=1}^{n} \frac{\vec{q}_{\rho-1}\vec{p}_\rho}{\vec{r}_\rho \vec{p}_\rho} \frac{|\vec{r}_\rho|}{v_\rho} ,$$

consequently the time gradient is given bv

$$\frac{1}{2}\frac{dT}{dy} = \frac{1}{|\vec{q}|} \sum_{\rho=1}^{n} \frac{\vec{q}_{\rho-1}\vec{p}_\rho}{\vec{r}_\rho \vec{p}_\rho} \cdot \frac{v_{\rho+1}}{v_\rho^2}$$

$$= \frac{1}{\vec{q}|} \left\{ \sum_{\rho=1}^{n} \frac{v_{\rho+1}}{v_\rho^2} A_\rho + \frac{v_{\rho+1}}{v_\rho^2} \sum_{\tau=1}^{\rho} (-1)^\tau \sum_{\mu_1 < .. < \mu_\tau < \rho} A_{\mu_1} a_{\mu_1 \mu_2} \ldots . a_{\mu_{\tau-1} \mu_\tau} a_{\mu_\tau \rho} \right\} \quad (4)$$

Summing up with regard to τ, we have to indicate the lower limit only, as the required upper limit is maintained automatically by the assumptions. By gathering all terms on the right hand side of equation (4) containing the same A_μ we have

$$\frac{1}{2} | \vec{q} \; \frac{dT}{dy} = \sum_{\mu=1}^{n} A_\mu K_\mu .$$

We assert

$$K_\mu = \frac{V_{\mu+1}}{V_\mu^2} - \sum_{\lambda=\mu+1}^{n} a_{\mu\lambda} K_\lambda .$$

This relation is proved by induction. Beginning with $\mu = n$, we get

$$K_n = \frac{1}{V_n},$$

a correct relation as follows from (4); for in the second sum in (4) there is no term which has A_n as a factor.

Making use of

$$K_\lambda = \frac{V_{\lambda+1}}{V_\lambda^2} + \sum_{\rho=1}^{n} \frac{V_{\rho+1}}{V_\rho^2} \sum_{\tau=1}^{\cdot\cdot} (-1)^\tau \sum_{\lambda<\mu_2<\ldots<\mu_\tau<\rho} a_{\lambda\mu_2} \ldots a_{\mu_{\tau-1}\mu_\tau} a_{\mu_\tau\rho},$$

we have

$$\frac{V_{\mu+1}}{V_\mu^2} - \sum_{\lambda=\mu+1}^{n} a_{\mu\lambda} K_\lambda = \frac{V_{\mu+1}}{V_\mu^2} - \sum_{\lambda=\mu+1}^{n} a_{\mu\lambda} \left\{ \frac{V_{\lambda+1}}{V_\lambda^2} + \sum_{\rho=1}^{n} \frac{V_{\rho+1}}{V_\rho^2} \sum_{\tau=1}^{\cdot\cdot} (-1)^\tau \cdot \right.$$

$$\left. \sum_{\lambda<\mu_2<\ldots<\mu_\tau<\rho} a_{\lambda\mu_2} \ldots a_{\mu_\tau\rho} \right\} = \frac{V_{\mu+1}}{V_\mu^2} - \sum_{\rho=\mu+1}^{n} \frac{V_{\rho+1}}{V_\rho^2} a_{\mu\rho} +$$

$$+ \sum_{\rho=1}^{n} \frac{V_{\rho+1}}{V_\rho^2} \sum_{\tau'=2}^{\cdot\cdot} (-1)^{\tau'} \cdot \sum_{\mu<\mu_2<\ldots<\mu_{\tau'}<\rho} a_{\mu\mu_2} \ldots a_{\mu_{\tau'}\rho} = K_\mu, \text{ q. e. d.}$$

As will be proved by induction with respect to μ, we have

$$K_\mu = \frac{V_{\mu+1}}{V_\mu^2} D_\mu \cos\alpha_\mu .$$

Consequently it follows that

$$\frac{1}{2}\frac{dT}{dy} = \frac{1}{|\vec{q}|} \sum_{\mu=1}^{n} \frac{V_{\mu+1}}{V_\mu^2} D_\mu \cos\alpha_\mu \frac{|\vec{q}| \sin\gamma_\mu \cos\delta_\mu}{\frac{V_{\mu+1}}{V_\mu} \cos\alpha_\mu} = \sum_{\mu=1}^{n} \frac{\sin\gamma_\mu \cos\delta_\mu}{V_\mu} D_\mu$$

or using again the indices (n)

$$\frac{1}{2}\frac{dT_n}{dy} = \sum_{\mu=1}^{n} \frac{\sin\gamma_\mu \cos\delta_\mu}{V_\mu} D_\mu^{(n)} \quad \ldots\ldots\ldots \quad (5)$$

This is the equation for the time gradient that we wished to derive. It still remains to prove the assertion

$$K_\mu = \frac{V_{\mu+1}}{V_\mu^2} D_\mu \cos\alpha_\mu$$

to be correct. For $\mu = n$ the relation becomes trivial:

$$K_n = \frac{1}{V_n} = \frac{V_{n+1}}{V_n^2} D_n \cos 0° .$$

Then we have by induction

$$K_\mu = \frac{v_{\mu+1}}{v_\mu^2} - \sum_{\lambda=\mu+1}^{n} \alpha_{\mu\lambda} \frac{v_{\lambda+1}}{v_\lambda^2} D_\lambda \cos\alpha_\lambda .$$

Because of

$$\alpha_{\mu\lambda} \frac{v_{\lambda+1}}{v_\lambda^2} \cos\alpha_\lambda = \frac{\vec{r}_\mu \vec{p}_\lambda}{\vec{r}_\lambda \vec{p}_\lambda} \frac{v_{\lambda+1}}{v_\lambda^2} \cos\alpha_\lambda = \frac{\vec{r}_\mu \vec{p}_\lambda}{v_\lambda},$$

we obtain by (1)

$$K_\mu = \frac{v_{\mu+1}}{v_\mu^2} - \sum_{\lambda=\mu+1}^{n} \frac{D_\lambda \vec{p}_\lambda}{v_\lambda} \vec{r}_\mu = \frac{v_{\mu+1}}{v_\mu^2} - \frac{\vec{r}_\mu \vec{r}_{\mu+1}}{v_{\mu+2}}.$$

As further

$$\frac{\vec{r}_\mu}{v_{\mu+1}} = \frac{D_\mu \vec{p}_\mu}{v_\mu} + \frac{\vec{r}_{\mu+1}}{v_{\mu+2}},$$

and consequently

$$\frac{\vec{r}_\mu \vec{r}_{\mu+1}}{v_{\mu+1}} = \frac{D_\mu v_{\mu+2} \cos\beta_\mu}{v_\mu v_{\mu+1}} + \frac{v_{\mu+2}}{v^2_{\mu+1}},$$

it follows that

$$K_\mu = \frac{v_{\mu+1}}{v_\mu^2} \left\{ 1 - \frac{v_\mu}{v_{\mu+1}} D_\mu \cos\beta_\mu - \frac{v_\mu^2}{v^2_{\mu+1}} \right\},$$

and by making use of easy trigonometrical transformations and of the formula

$$D_\mu = \cos\alpha_\mu - \frac{v_\mu}{v_{\mu+1}} \cos\beta_\mu = \frac{\sin(\beta_\mu - \alpha_\mu)}{\sin\beta_\mu}$$

and

$$\frac{\sin\alpha_\mu}{\sin\beta_\mu} = \frac{v_\mu}{v_{\mu+1}},$$

the assertion follows.

IV—Determination of the Strike Lines and the Inclination of the Layers. Relations between the Direction of the Isochronic Lines and the Strike Line of a Reflecting Plane

By equation (5) the time gradient is given with respect to its dependence on its direction and on the velocities and strike lines and inclination of the layers. This follows from:

$$\vec{r}^{(n)}_\mu = v_{\mu+1} \sum_{\lambda=\mu}^{n} \frac{D^{(n)}_\lambda \vec{p}_\lambda}{v_\lambda}$$

$$r_\mu \vec{p}_\mu = \frac{v_{\mu+1}}{v_\mu} D^{(n)}_\mu + v_{\mu+1} \sum_{\lambda=\mu+1}^{n} \frac{D^{(n)}_\lambda \vec{p}_\lambda \vec{p}_\mu}{v_\lambda}$$

$$\frac{v_{\mu+1}}{v_\mu}\cos\alpha_\mu^{(n)} = \frac{v_{\mu+1}}{v_\mu} D_\mu^{(n)} + v_{\mu+1}\sum_{\lambda=\mu+1}^{n} \frac{D_\lambda^{(n)}\,\vec{p}_\lambda\,\vec{p}_\mu}{v_\lambda}$$

$$\cos\beta_\mu^{(n)} = v_{\mu+1}\sum_{\lambda=\mu+1}^{n} \frac{D_\lambda^{(n)}\,\vec{p}_\lambda\,\vec{p}_\mu}{v_\lambda}$$

and

$$D_\mu^{(n)} = \cos\alpha_\mu^{(n)} - \frac{v_\mu}{v_{\mu+1}}\cos\beta_\mu^{(n)},$$

i.e. from the fact that the $D_\mu^{(n)}$, too, are functions of the velocities, directions of trend and inclination of the layers. Now, if we assume the layer velocities and the strike lines and the inclination of the upper n-1 boundaries to be known, the time gradient will be a function of direction of the trend and inclination of the n-th interface and of the direction in which it is considered, only. Taking the time gradient for two directions, we obtain two equations for determining the strike lines and the inclination of the n-th layer, the time gradients being known from the isochronic maps. For instance, we have the formulas

$$\frac{1}{2}\left(\frac{dT}{dy}\right)_{\delta_1=0} = \sum_{\mu=1}^{n} \frac{\sin\gamma_\mu\cos\delta_{1\mu}}{v_\mu} D_\mu^{(n)} \quad \ldots\ldots\ldots \quad (6_1)$$

$$\frac{1}{2}\left(\frac{dT}{dy}\right)_{\delta_1=\frac{\pi}{2}} = \sum_{\mu=1}^{n} \frac{\sin\gamma_\mu\sin\delta_{1\mu}}{v_\mu} D_\mu^{(n)} \quad \ldots\ldots\ldots \quad (6_2)$$

by taking the time gradient in the direction of dip or of the trend of the first reflecting plane, respectively. The time gradient in the direction of the isochronic lines of the n-th boundary is zero, by definition of the isochronic lines, and therefore we have the equation

$$\sum_{\mu=1}^{n} \frac{\sin\gamma_\mu\cos\delta_\mu^0}{v_\mu} D_\mu^{(n)} = 0 \quad \ldots\ldots\ldots \quad (6_3),$$

which may be used instead of the equation (6_1) or (6_2) for computing the data of the n-th plane. In (6_3) δ_μ^0 is the angle between the direction of dip of the μ-th interface and the isochronic lines. In the case of the directions of trend of the first n-1 layers being identical, the relation (6_2) is especially simple, namely

$$\frac{1}{2}\left(\frac{dT}{dy}\right)_{\delta_1=\frac{\pi}{2}} = \frac{\sin\gamma_n\sin\delta_{1n}}{v_n} \quad \ldots\ldots\ldots\ldots \quad (6'_2).$$

Of course, for reflection seismic interpretation, the expressions $D_\mu^{(n)}$, in particular should be simplified by certain approximations. Such simplifications may be based on the fact that generally the difference between the angle of refraction and the angle of incidence is small. In the above-mentioned paper by R. Bading and myself, which will be published shortly, it is shown by an example how correct results may be obtained more quickly in spite of the relatively complicated formulas.

Finally, let us consider the relations between the isochronic lines and the strike lines of a deeper layer. For this purpose we use equation (63) and confine ourselves to the case of two layers. Equation (63) is simplified in this case as follows:

$$\frac{\sin \gamma_1}{v_1} \cos \delta_1^0 \frac{\sin (\beta - \alpha)}{\sin \beta} + \frac{\sin \gamma_2}{v_2} \cos (\delta_1^0 - \delta) = 0$$

(δ = angle between the strike lines of the two layers).

First we state the strike lines of the layers to have the same direction if, and only if, the isochronic lines have the same direction. It is a trivial statement that the isochronic lines have the same direction if the assumption is fulfilled. Inversely, if the isochronic lines have identical directions, i.e. if $\delta_1^0 = \frac{\pi}{2}$, it follows that $\frac{\sin \gamma_2}{v_2} \sin \delta = 0$, and consequently $\delta = 0$, q.e.d. But it is easily seen that the isochronic lines do not give the direction of the trend, for the direction of the isochronic and strike lines being identical is equivalent to $\delta_1^0 - \delta = \frac{\pi}{2}$, i.e.

$\frac{\sin \gamma_1}{v_1} \cos \delta_1^0 \frac{\sin (\beta - \alpha)}{\sin \beta} = 0$, being equivalent to $\delta_1^0 = \frac{\pi}{2}$ $(\gamma_1 \neq 0!)$. Thus we may say that the isochronic lines indicate different directions of the trend of the layers, but they do not give them directly.

We will complete these considerations by giving some curves which show some functional connections between the direction of the strike lines and the isochronic lines of the second lower horizon. The figures 3, 4 and 5 show the angle between these directions as a function of the angle between the directions of dip of the two layers (Fig. 4), as a function of the inclination of the second horizon (Fig. 5), and as a function of the ratio of the two layer-velocities $\frac{v_1}{v_2}$ (Fig. 6), the other variables having constant values of any kind. These curves may warn anybody not to make use of the direction of the isochronic

I $\gamma_1 = 30°$ $\gamma_2 = 45°$ $v_1 : v_2 = 2:3$
II $\gamma_1 = 10°$ $\gamma_2 = 40°$ $v_1 : v_2 = 2:3$

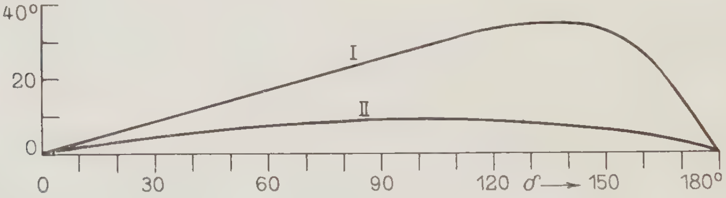

Fig. 4.

lines as "direction of the trend", as generally large mistakes arise in constructing according to such a procedure.

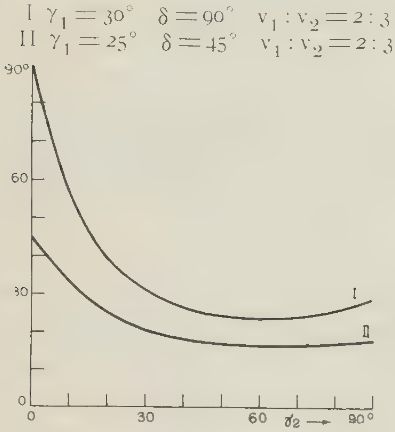

Fig. 5.

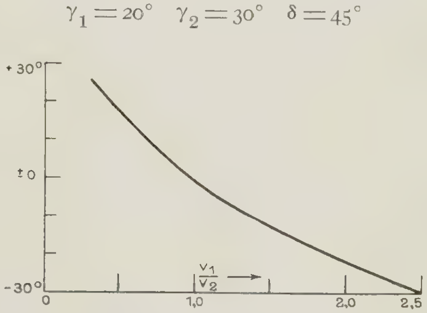

Fig. 6.

V—Construction of the Contour Map of a Reflecting Horizon from the Corresponding Isochronic Map

Having now determined strike lines and inclination of the layers successively, the interfaces are constructed by using normal rays vertically projected on the surface, as mentioned in the introduction. Assuming the upper n-1 planes (i.e. their contour maps) to be constructed, we will sketch a contour map of the n-th interface. The projection of a ray normally reflected at this horizon consists of n segments, the μ-th member of which forms the angle $\eta_{\mu}^{(n)}$ with the direction of dip of the first reflecting plane, and the length of which is denoted by $l_{\mu}^{(n)}$. These angles and lengths are to be expressed by means of the quantities already determined. From (2′) and (6_1) it follows that

$$\sin\zeta_{\mu}^{(n)}\cos\eta_{\mu}^{(n)} = \frac{v_{\mu}}{2}\left(\frac{dT_n}{dy}\right)_{\delta_1=0} - v_{\mu}\sum_{\lambda=1}^{\mu-1}\frac{\sin\gamma_{\lambda}\cos\delta_{1\lambda}\,D_{\lambda}^{(n)}}{v_{\lambda}} \quad . \; . \quad (7_1)$$

Especially in the case of $\mu = 1$, this relation is very easy.

$$\sin\zeta_1^{(n)}\cos\eta_1^{(n)} = \frac{v_1}{2}\left(\frac{dT_n}{dy}\right)_{\delta_1=0} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (7_2)$$

$T_{\mu-1}^{(n)}$ ($\mu \leq n$) being the depth of the point at which the (μ-1)th plane is pierced by the ray, and $T_{\mu}^{(n)\prime}$ the depth of the μ-th interface vertically below this point, it follows immediately that

$$l_{\mu}^{(n)} = \frac{T_{\mu}^{(n)\prime} - T_{\mu-1}^{(n)}}{\operatorname{ctg}\zeta_{\mu}^{(n)} - \operatorname{tg}\gamma_{\mu}\cos(\eta_{\mu}^{(n)} - \delta_{1\mu})} \; .$$

The depth of the point at which the ray meets the next horizon is given by

$$T^{(n)}_{\mu} = T^{(n)}_{\mu-1} + l^{(n)}_{\mu} \operatorname{ctg} \zeta^{(n)}_{\mu} .$$

Finally, we have

$$l^{(n)}_{n} = \sin \zeta^{(n)}_{n} v_n (t_n - t_n')$$

in which t_n is half the time needed by the normally reflected ray, and t_n' the time needed for the ray path up to the (n)th layer already constructed. The angle between $l^{(n)}_{n}$ and the direction of dip of the first interface is δ_{1n}. The depth of the nadir of the ray is

$$T^{(n)}_{n-1} + \cos \zeta^{(n)}_{n} v_n (t_n - t_n') .$$

Generally, in order to simplify the construction, one should include as many strata as possible and treat them as a single layer with an average velocity.

VI—The Special Case of Corresponding Strike Lines of the Layers, Tuchel's Formulas

If the strike lines of the layers have the same direction, it is not necessary to construct contour maps of the reflecting planes, but a profile may be drawn perpendicular to the general trend. In order to obtain the intersecting line of the profile and the n-th interface, there are to be constructed the first n-1 interfaces, and then the angle of dip of the ray normally reflected on the n-th reflecting bed still remains to be known. For the ray propagates through the layers in the plane perpendicular to the strike lines according to Snel's refraction law. As in this case $\eta_1^{(n)} = 0$, the angle of dip is given by

$$\sin \zeta_1^{(n)} = -\frac{v_1}{2}\left(\frac{dT_n}{dy}\right)_{\delta_1=\pi} , \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8_1)$$

which equation follows from (7_2). (8_1) is the formula given by de Caleya and myself.

A similar formula for the same angle is given by Tuchel [3]

$$\sin \zeta_1^{(n)} = - v_1 \left(\frac{dT^*_n}{dy}\right)_{\delta_1=\pi,\ x=0} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8_2)$$

In this formula $T^*_n(y)_{\delta_1=\pi}$ is the time for a ray running from a shotpoint Sp to the n-th horizon and then to a geophone which is at a distance x from the shotpoint in the direction $\delta_1 = \pi$ (Fig. 7). Now, these functions T_n, T_n^* are related to each other, and in this manner using (8_1), Tuchel's formula (8_2) is proved.

Let $T_n(u, x)$ be the time for a ray reflected at the n-th horizon which is running from a shotpoint with the co-ordinate u to a geophone at the point with the co-ordinate $u + x$. Then the following relations are valid:

$$T_n(u) = T_n(u, 0) \qquad T_n^*(x) = T_n(u_0, x),$$

and the formulas become

$$\sin \zeta_1^{(n)} = -\frac{v_1}{2} \frac{\partial}{\partial u} \left(T_n(u, 0)_{\delta_1 = \pi}\right) \quad \ldots\ldots\ldots \quad (8_1')$$

$$\sin \zeta_1^{(n)} = -v_1 \frac{\partial}{\partial x} \left(T_n(u_0, x)_{\delta_1 = \pi}\right)_{x = 0} \quad \ldots\ldots \quad (8_2')$$

Whereas in our formula for the angle of dip the derivative of the time for normally reflected rays with respect to the co-ordinate of the shotpoint is used,

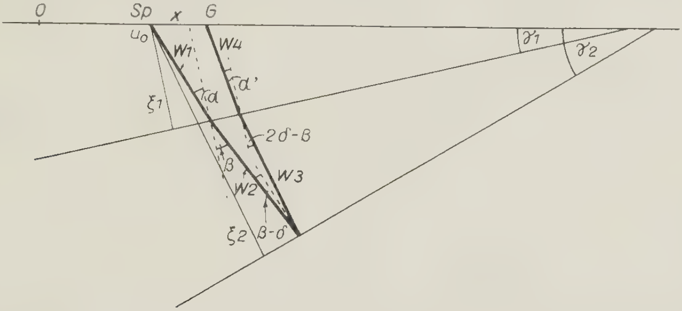

Fig. 7.

Tuchel's construction makes use of the slope of the time-distance curve at the shotpoint.

Now Tuchel's formula is to be proved by induction with respect to the number n of the layers. Firstly, for n = 1 the following relation is well known:

$$[T_1(u, x)]^2 = \frac{1}{v_1^2} (x^2 + 4\xi_1^2 - 4\xi_1 x \sin \gamma_1)$$

ξ_1 is the distance of the shotpoint u from the first interface. It follows that

$$2\, T_1(u, O) \left(\frac{\partial T_1}{\partial x}\right)_{x = 0} = \frac{1}{v_1^2} (-4\, \xi_1 \sin \gamma_1)$$

$$\left(\frac{\partial T_1}{\partial x}\right)_{x = 0} = -\frac{\sin \zeta_1^{(1)}}{v_1} \frac{\frac{\xi_1}{v_1}}{T_1(u, 0)} = -\frac{\sin \zeta_1^{(1)}}{v_1}.$$

Then we assume the formula (8_2) to be correct for n-1 layers, and prove it for n layers (Fig. 8).
It is

$$T_n(u_0, x) = \frac{\xi_1}{v_1 \cos \alpha} + \frac{\xi_1 - x \sin \gamma_1}{v_1 \cos \alpha'} + T^{(n-1)},$$

$T^{(n-1)}$ being the time for the real ray-path through the deeper n-1 layers.

Thus we have

$$\left(\frac{dT_n}{dx}\right)_{x=0} = \frac{\xi_1 \sin\alpha_0}{v_1 \cos^2\alpha_0} \left\{ \left(\frac{d\alpha}{dx}\right)_{x=0} + \left(\frac{d\alpha'}{dx}\right)_{x=0} \right\} - \frac{\sin\gamma_1}{v_1 \cos\alpha_0} + \left(\frac{dT^{(n-1)}}{dx}\right)_{x=0} .$$

Now we will enter into a consideration of the function $T^{(n-1)}$; we may think of $T^{(n-1)}$ as a function T_{n-1}, if we consider the first reflecting horizon to be the surface and the points at which the ray pierces the first interface to be "shotpoints" or "geophone-points" respectively. Thus $T^{(n-1)}$ is a function of two variables U, X; U may be normed so that U = O is the meeting place of the normally reflected ray and the first plane. The total differential of $T^{(n-1)}$ is

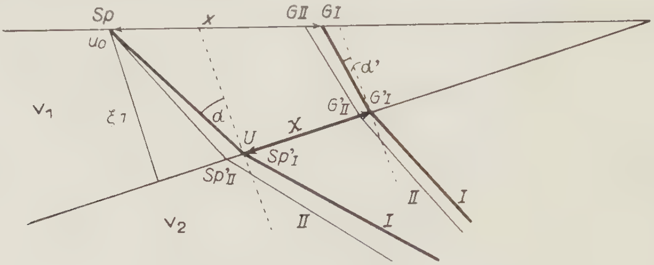

Fig. 8.

$$dT^{(n-1)}(U, X) = \frac{\partial T^{(n-1)}(U, X)}{\partial U} dU + \frac{\partial T^{(n-1)}(U, X)}{\partial X} dX .$$

From this, it follows that

$$\left(\frac{dT^{(n-1)}(x)}{dx}\right)_{x=0} = \left(\frac{\partial T^{(n-1)}(U, O)}{\partial U}\right)_{u=0} \left(\frac{dU}{dx}\right)_{x=0} + \left(\frac{\partial T^{(n-1)}(O, X)}{\partial X}\right)_{x=0} \left(\frac{dX}{dx}\right)_{x=0} .$$

We have

$$\left(\frac{\partial T^{(n-1)}(U, O)}{\partial U}\right)_{u=0} = -\frac{2\sin\beta_0}{v_2} = -\frac{2\sin\alpha_0}{v_1} \quad \ldots\ldots \quad (9_1)$$

$$\left(\frac{\partial T^{(n-1)}(O, X)}{\partial X}\right)_{x=0} = -\frac{\sin\beta_0}{v_2} = -\frac{\sin\alpha_0}{v_1} \quad \ldots\ldots\ldots \quad (9_2)$$

As $U = \xi_1 . \mathrm{tg}\,\alpha + \text{const.}$,
it follows that

$$\left(\frac{dU}{dx}\right)_{x=0} = \frac{\xi_1}{\cos^2\alpha_0} \left(\frac{d\alpha}{dx}\right)_{x=0} \quad \ldots\ldots\ldots\ldots \quad (9_3)$$

From

$$X = \cos\gamma_1 \left\{ x - \frac{\xi_1 \,\mathrm{tg}\,\alpha}{\cos\gamma_1} + \frac{\xi_1 - x\sin\gamma_1}{\cos\gamma_1} \mathrm{tg}\,\alpha' \right\}$$

it follows that

$$\left(\frac{dX}{dx}\right)_{x=0} = \cos\gamma_1 - \frac{\xi_1}{\cos^2\alpha_0} \left\{ \left(\frac{d\alpha}{dx}\right)_{x=0} - \left(\frac{d\alpha'}{dx}\right)_{x=0} \right\} \sin\gamma_1 \,\mathrm{tg}\,\alpha_0 \ldots\ldots \quad (9_4)$$

Finally it may be seen by induction that the following relation is valid:

$$\left(\frac{d\alpha}{dx}\right)_{x=0} = -\left(\frac{d\alpha'}{dx}\right)_{x=0}$$

For we have

$$\left(\frac{d\alpha}{dx}\right)_{x=0} = \frac{v_1}{v_2}\frac{\cos\beta_0}{\cos\alpha_0}\left(\frac{d\beta}{dx}\right)_{x=0}$$

$$\left(\frac{d\alpha'}{dx}\right)_{x=0} = \frac{v_1}{v_2}\frac{\cos\beta_0}{\cos\alpha_0}\left(\frac{d\beta'}{dx}\right)_{x=0}$$

$$\left(\frac{d\beta}{dx}\right)_{x=0} = \left(\frac{d\beta}{dX}\right)_{X=0}\left(\frac{dX}{dx}\right)_{x=0} = -\left(\frac{d\beta'}{dX}\right)_{X=0}\left(\frac{dX}{dx}\right)_{x=0} = -\left(\frac{d\beta'}{dx}\right)_{x=0}.$$

With regard to all these relations, the correctness of Tuchel's formulas is immediately evident:

$$\left(\frac{dT_n}{dx}\right)_{x=0} = -\frac{\sin\gamma_1}{v_1\cos\alpha_0} - \frac{2\sin\alpha_0}{v_1}\frac{\xi_1}{\cos^2\alpha_0}\left(\frac{d\alpha}{dx}\right)_{x=0} -$$

$$-\frac{\sin\alpha_0}{v_1}\left\{\cos\gamma_1 - \frac{2\,\xi_1}{\cos^2\alpha_0}\left(\frac{d\alpha}{dx}\right)_{x=0} - \sin\gamma_1\,\mathrm{tg}\,\alpha_0\right\}$$

$$= -\frac{1}{v_1\cos\alpha_0}\left\{\sin\gamma_1 + \sin\alpha_0\cos\alpha_0\cos\gamma_1 - \sin^2\alpha_0\sin\gamma_1\right\}$$

$$= -\frac{1}{v_1}\sin(\gamma_1 + \alpha_0) = -\frac{\sin\zeta_1^{(n)}}{v_1}, \text{ q. e. d.}$$

LITERATURE

(1) THEODOR KREY, "Les reflections à l'intérieur des dômes de sel et leur importance pour les recherches de pétrole", Proceedings of the Third World Petroleum Congress.

(2) J. F. DE CALEYA, H. CLOSS, H. DÜRBAUM, "Zur Berücksichtigung der Brechung in der Reflexionsseismik", Erdöl und Kohle, December 1952.

(3) G. TUCHEL, Seismische Messungen, Taschenbuch für angewandte Geophysik.

BOOK REVIEW

C. Hewitt Dix. — Seismic Prospecting for Oil.

414 pp., 175 figs. Price $ 6.75. Published by Harper & Brothers, New York.

Dr. Dix covers the subject in five sections:

I. Introduction and General Orientation.
II. Routine Seismology.
III. Interpretations.
IV. Refraction Prospecting.
V. The Physical Processes Involved.

Each of these broad subjects is examined in an objective and logical fashion. They are broken down into sections or sub-sections, many of which are developments from diagrams of unusual clarity, drawn in a good style with their associated formulae below. The treatment (including the mathematical work) is such that the majority of those to whom the book is addressed can read it readily, with but little reference to other books in order to follow the writer's train of thought.

A striking feature of the book is that many of the problems which are discussed in the field offices of seismograph crews here get adequate and interesting treatment. The writer is clearly based on a wide and sympathetic appreciation of the difficulties which beset the exploration seismologist in the field.

In the Preface it is remarked that exploration geologists have been uppermost in the writer's mind. If this were truly the case, then it would be necessary to pause from time to time in the account, to survey the matter treated from the view-point of the practising geologist, to relate that part of seismic study to the realities of his own science, using his own vocabulary.

The reviewer does not find that all of the subjects dealt with have been brought to the same level of usefulness. Thus, while the accounts of velocity measurements and of reflection work generally seem rather complete, that dealing with refraction is much less so. The writer intends the chapter on Line refraction work for members of reflection seismic parties who have to do an occasional refraction job—but they must carry their interpretation as far as a regular refraction crew.

Production of the volume is pleasing, and almost free from errors. The bibliography is excellent.

The book is an excellent one on its subject.

A. A. Fitch

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

44. *Exploration and Refining Lead Rush of Technical Advances in all Branches.*
C. O. Nickle & L. O. Rowland, Oil in Canada, Vol. 3, No. 2, pp. 18-26, 1951.

Advances in the design and use of portable geophysical equipment and the use of new types of vehicles made possible year-round operations of seismograph crews in 1950 in the Muskeg Country. Two versions of superlight shot hole drilling rigs, portable recording equipment, and the development of the PSU-11 unit as a set of miniature seismic instruments are described. Use of a helicopter and the airborne magnetometer is also described. Radioactivity logging had its first full year of operation in Canadian oil fields in 1950. Conclusions from available data indicate the neutron curve is a highly accurate quantitative method of porosity evaluation and that in a limestone or dolomite bed in a known field with core analysis available from one well the evaluation may be applied satisfactorily to any well in the field.

45. *Report of the Special Committee on the Geophysical and Geological Study of the Continents, 1949-1950.*
G. P. Woolard, Am. Geophys. Union Trans., Vol. 32, No. 1, pp. 96-105, 1951.

Gravity, magnetic, seismic, and tectonic investigations, chiefly in North America, are reviewed.

46. *Geophysical Frontiers.*
G. E. Wagoner, Oil & Gas Journal, Vol. 49, No. 51, pp. 119-122, April 26, 1951.
Geophysics, Vol. 16, No. 3, pp. 385-390, July, 1951.

The author of this paper expresses clearly the efforts which are needed in all types of geophysical methods if the geophysicist is to be in a position to cope with the demands of the future. This is a most refreshing paper and, while it pin-points our neglect of certain aspects of geophysical surveying in the past, it leaves the reader with feelings of encouragement and enthusiasm.

47. *Geophysical Activity in 1950.*
E. A. Eckhardt, Oil & Gas Journal, Vol. 49, No. 51, pp. 106-107, April 26, 1951.
Geophysics, Vol. 16, No. 3, pp. 391-400, July, 1951.

The article is a review of the activities of geophysical exploration crews. Seismic crews, which numbered 520 in 1949, had a drop of 6.9 % in 1950, whereas gravity crews numbered 110 in 1950 — 25.8 % less than in 1949. Charts are given showing the distribution of exploration over the U.S. and the whole world. The estimated cost of work during 1950 is $ 205,000,000.

Canada's activity rose from 9,54 % of the world total in 1949 to 15.13 % in 1950, whereas U.S. activity dropped from 74.87 % in 1949 to 68.01 % in 1950. The indications favour a world-wide increase in geophysical activity for the future.

48. *Geophysics and Dollars.*
Petroleum, Vol. 14, No. 10, p. 260, October, 1951.

Oil technicians in Britain and Holland are collaborating with British manufacturers of petroleum equipment to make the expensive precision instruments used for seismic surveys for oil. Some 14 sets of these instruments, once manufactured exclusively in the U.S., have been completed this year from parts manufactured in Britain — at a considerable saving in dollars. The total cost involved is about £ 200,000 and thus a saving of nearly U.S. $ 600,000 has been effected.

49. *Geophysical Costs Outrun Prices.*
J. E. Kastrop, World Oil, Vol. 132, No. 6, pp. 55-58, May, 1951.

The facts are given concerning the business status of the American geophysical contractor. *World Oil* surveyed a cross-section of geophysical contracting companies who specialise in seismograph exploration. The results shown are averages, and represent the condition of the geophysical contractors as a whole. Prominent company executives were interviewed and their thoughts are incorporated in this study. The wide deviation between seismograph costs and income is placing the contractor in a precarious position, according to these findings.

50. *Accuracy Factors in Geophysical Prospecting.*
N. J. Smith, World Oil, Vol. 132, No. 6, pp. 73-78, May, 1951.

As between the three methods considered, the magnetic method, though fastest and cheapest, is the least definite for petroleum exploration. The seismic method, though the slowest and the most expensive, is the most precise and definitive, while gravity lies between the two, but closer to the magnetic method than the seismic.

With each method the accuracy or reliability in a particular case is a function of the amount of subsidiary and corollary geophysical and geological data available, of instrument quality, of the calibre of the personnel involved, and of the time allotted to the problem.

51. *Middle East Oil.*
G. M. Lees, Oil Forum, Vol. 5, No. 7, pp. 245-246, July, 1951.

The task of discovering new oilfields in Iran is made more difficult by the presence of huge salt formations which act as a lubricating medium between the higher strata and the lower limestones in which oil is found.

So far the refraction method of exploration has been quite successful, but the reflection method has yielded little.

52. *The Search for Oil in Australia.*
World Petroleum, Vol. 22, No. 10, pp. 60-61, September, 1951.

Though some £ 11,000,000 have been spent in the search for oil in Australasia, none of any significance has yet been found. The search goes on more intensively than ever. The Federal Bureau of Mineral Resources, Geology and Geophysics have mapped huge areas by means of aerial surveys. The more detailed mapping has been carried out by geologists and private oil companies. This article goes into some detail of the operations in Australasia and New Guinea.

53. *Exploration and Drilling.*
World Petroleum, Vol. 22, No. 10, pp. 43-47, September, 1951.

The world-wide rise in the demand for petroleum products is acting as a powerful stimulus to exploration and drilling. This article describes world-wide activity in those two fields.

54. *Geophysical Surveys on the Bahama Banks.*
C. S. Lee, Jrnl. Inst. Petroleum, Vol. 37, No. 334, October, 1951.

The paper reviews the geophysical methods employed in the great areas of shallow water on the Bahama Banks. Previous geophysical and geological work throughout the region is reviewed, discussed, and related to the most up-to-date work in Abaco, Eleuthera, and Ragged Island. As a result of this revision, explanations of structural build-ups and processes of sedimentation are advanced which differ considerably from explanations advanced by previous students of the area.

55. *Exploration Critique.*
P. C. Ingalls, Oil & Gas Jrnl., Vol. 50, No. 29, p. 39, Nov. 22, 1951.

Dr. B. B. Weatherby, Amerada Petroleum Corp., Tulsa, told geophysicists at Dallas that geophysical crews are not using all of the latest instruments, or are not using them to the best advantage because of the lack of trained men. Geophysical surveys need to be planned more thoroughly to prevent wastage.

Too much work is being carried out in old producing areas. With new techniques a lot of new finds are resulting, but they are comparatively small ones. The search for large new fields should be extended to the north central and Rocky Mountain states.

More information may be extracted from seismic records. This information is essential to cut the number of dry wildcats being drilled.

56. *Current Trends in Seismic Exploration.*
S. Harris, Oil Forum, Vol. 5, No. 11, pp. 419-420, November, 1951.

Korea and threatened widening of hostilities, coupled with cessation of Iranian production sends exploration in N. America to all-time high. Application of seismograph has already increased by 20% this year.

During recent years one out of 20 wildcats based on geology alone has struck oil, whereas one of every six based on geophysical data alone has been successful. A combination of geophysics and geology was attended by success in one well out of five.

The author goes into some detail concerning geophysical activities in the U.S.A. He believes that exploration with the seismograph in the U.S. and neighbouring countries will continue during 1952 at least at the level of the last half of 1951, and with possible expansion from the standpoint of the number of crews in actual operation during 1951.

57. *Hydrostatic Level for Elevation Surveying.*
K. C. Krumrine & J. E. Palmer, Geophysics, Vol. 16, No. 3, pp. 486-493, July, 1951.

A hydrostatic level for elevation surveying has been developed which indicates differences in elevation by measuring the head of a column of water. It is essentially a differential pressure gauge connected by a length of water-filled plastic tubing to a water reservoir. The instrument is described and the results of a field test on 73 miles of traverse are given. A probable error of about 6 cm. and a maximum error of 33 cm. were found for closed loops of 3 to 5 miles after proration of closure errors. On unsupported traverses of 3 to 5 miles, application of a temperature correction appeared desirable and resulted in a probable error of about 10 cm. and a maximum error of 52 cm. The range of the instrument is from minus to plus 10 metres and the least count is 2 cm. It is read to the nearest cm.

58. *Geophysics — Annual Review 1950.*
S. F. Kelly, Mining Eng. (U.S.A.), Vol. 190, No. 2, pp. 136-140, February, 1951.

An excellent review of the application of Geophysics in 1950 both in the Mining and the Oil Industries. The author is Secretary, Geophysics Subdivision, A.I.M.E., and also Chairman, Geophysics Subdivision, C.I.M., and is therefore in a position to be well informed on geophysical activities.

59. *Geophysical Evaluation of the Marfa Basin of Texas.*
J. H. Wilson, Geophysics, Vol. 16, No. 3, pp. 494-498, 1951.

The Marfa basin presents a difficult exploration problem because of the larva flows at or near the surface. Gravity, magnetic and seismic surveys have been made since 1943. A comprehensive exploration programme would include aerial mapping, airborne magnetometer and radiation surveys, a gravity meter survey to outline the basin, and seismic surveys to explore anomalies indicated by other methods. Data on the density and susceptibility of typical rocks are given.

60. *Geophysical History of the Delhi Field, Richland, Franklin, and Madison Parishes, Louisiana.*
W. E. Hollingsworth, Geophysics, Vol. 16, No. 2, pp. 185-191, April, 1951.

The geophysical history of the Delhi Field started in 1938 when a Gulf gravity crew entered the area. In early 1940 results of drilling to the east indicated the absence of Tuscaloosa beds and a possible pinchout. In 1944 a seismograph crew under contract to Sun Oil Co. and C. H. Murphy entered the area. A small closure was found and drilled. Production was established in 1944 from Paluxy beds.

61. *Regional Geology and Geophysics of the Ark-La-Tex Area.*
C. L. Bryan, Geophysics, Vol. 16, No. 3, pp. 401-415, July, 1951.

The boundaries of the Ark-La-Tex area are arbitrarily defined and the exploration history of the area briefly reviewed. A Basal Upper Cretaceous structure map and two stratigraphic cross-sections illustrate the regional tectonic movements contributing to the formation of the East Texas basin, the North Louisiana basin and the intervening Sabine Uplift. Exploration objectives and problems and the relation of magnetic and gravity anomalies and axes with regional geologic trends and structure are discussed. It is pointed out that the piercement dome type structure offers an almost untested field for further exploration. Illustrations include a vertical intensity magnetic map with contour interval of 100 gammas, a Bouguer gravity map with contour interval of 5 milligals and type seismograph records.

62. *Anglo-Iranian's Prospecting Activities.*
Petroleum Times, Vol. 56, No. 1422, p. 81, February 8, 1952.

A short summary of the search for oil by the A.I.O.C. in Sicily, Nigeria, Trinidad, the Gulf of Paria, East Africa, North Africa, Papua, Switzerland and the United Kingdom.

63. *Exploration gets Results in Saudi Arabia.*
D. B. Ficher & M. P. Yackel, Oil Gas J., Vol. 50, No. 33, p. 208, Dec. 20, 1951.

During the past few years Aramco's exploration activity has been intense and diversified. Currently the exploration department has in the field the following operations: Three surface mapping parties, two triangulation parties, two gravimeter — magnetometer parties, two seismograph parties, and three structure drill parties using six rigs. Two-way radio communication is maintained continuously between all field parties and the Dhahran base.

64. *Oil Exploration in Western New Guinea.*
Oil Gas J., Vol. 50, No. 33, pp. 305-308, December 20, 1951.

The Netherlands New Guinea Petroleum Co. (N.N.G.P.M.) started exploring in 1936 when an aerial survey in the Bintuni Gulf was conducted. Bad weather caused this survey to last two years. Geological reconnaissance parties made a three years survey in the jungle and reduced the original prospecting area from 23.8 million acres to 20.1 million. From 40 Holweck pendulum stations, 6,000 torsion balance stations, and

2,200 Thyssen gravimeter stations a regional gravimetric picture was compiled. Detailed geologic work and seismic surveys to the total of 870 miles of profiles followed. Magnetometer measurements have since shown this method to be defective in certain places. The war ended operations.

In 1946 the geologists resumed work. The Klamono field told them that oil occurs in a Miocene reef limestone. Since 1948, three geological parties, two gravity parties and two seismic parties have been engaged. Reflections are poor and the only good refractor is a sedimentary limestone on which the reefs are supposed to have grown. The gravimeter is suitable only where the reefs occur at shallow depths. It is concluded that new seismic techniques, study of the exposed reef limestone area, and regional basin studies are needed to solve the intricate reef pattern.

65. *Petroleum Possibilities of Central America.*

W. F. Hoover, Oil Gas J., Vol. 50, No. 33, pp. 321-326, December 20, 1951.

Eight basins of sedimentation are present in Central America in which marine sediments of Tertiary age are deposited. Orogenic movements in Tertiary and post-Tertiary times have formed structures favourable for the accumulation of oil in all of these basins. The deposition of Tertiary sediments over pre-Tertiary structure forms conditions suitable for the formation of stratigraphic-type traps in which it is possible for oil to accumulate.

Four of these basins have indications of the possible presence of oil in commercial quantities in the form of showings obtained in test wells that have been drilled or in the form of oil and gas seepages on the outcrop of possible producing strata.

Geophysical prospecting will probably uncover subsurface structure suitable for the accumulation of oil and gas not apparent at the surface because of the unconformities in the stratigraphic section and locally by the cover of surface alluvium.

66. *Annual Survey of Geophysical Exploration 1950-1951.*

J. B. Macelwane, Geophysics, Vol. 16, No. 1, pp. 511-518, January, 1951.

This describes the results of a wide survey of the status of geophysical education in the U.S.A. Nearly 1,000 questionaires were sent out to 265 universities and colleges.

A steady growth is apparent when comparison is made with former surveys, and the importance of geophysical exploration is clearly being recognised.

The complete results of the survey are shown in a series of tables covering seven pages.

67. *Geology and Geophysics of the North Snyder Area, Scurry County, Texas.*

N. Clayton, Geophysics, Vol. 16, No. 1, pp. 1-13, January, 1951.

Discovery of the North Snyder reef in November, 1948, by Standard of Texas focused the attention of the oil industry on this part of West Texas and presented the geophysicist with the problem of how to locate other reefs of this type.

The North Snyder reef is unique in that reflected energy is obtained from the reef-shale contact in some parts of the field. Magnetic, gravimetric and seismic data are presented to show some of the effects to be expected from a reef of this type.

A number of electric log correlations are included in order to illustrate the geology of the field. From the electric logs it appears that the 'draping' effect is small above the thick Pennsylvanian shale section which compensates for the reef mass. Contour maps for the base of the Coleman Junction limestone and the top of the Canyon reef are presented.

68. *Problems of Seismic Work on Canadian Coral Reefs.*

O. Weiss, Oil in Canada, Vol. 3, No. 26, pp. 16-27, 1951.

Problems of oil prospecting in Canada differ from those in other parts of the world not only in geological problems involved but also in the conditions of rights for exploration and exploitation. Important oil production away from the foothills area has been obtained, only from coral reefs. The reflection method based on instrumentation and interpretation methods generally used in U.S. oilfields is not well suited to the problem. Varying thicknesses of glacial drift is another complicating factor. Development of a special high frequency and high recording velocity seismic method for rapid measurement of the thickness of the glacial drift is reported. The gravimetric method may ultimately be used, if a way can be found of correcting for irregular variations in thickness of drift which may mask anomalies caused by deeper structures.

69. *Geophysical Operations in the Canadian Bush.*
J. K. MacMillan, World Oil, Vol. 133, No. 7, pp. 81-84, December, 1951.

Northwest Seismic Surveys Ltd. started work in the muskeg country in 1949 with two geophysical crews. Since then the company has expanded so that it now has eleven crews in the field in Alberta. Experience in this time has promoted the development of equipment suitable for both the intensely cold winters and the summers, when the frozen muskeg thaws out to become a morass into which equipment and men may sink out of sight and beyond recovery. The winter operations of two crews early in 1950 are described in detail, showing all the difficulties encountered and how they were surmounted. The normal working season is from mid-November, to the end of March.

In Alberta there is an acute shortage of trained geophysical personnel. Consequently, companies have to offer competitive salaries to attract staff.

70. *Western Anakarko Basin Geophysical Problems.*
N. Clayton, World Oil, Vol. 133, No. 7, pp. 86-90, December, 1951.

Exploration in the Western Anadarko Basin has been slow in the past because of unsuitable geologic structures and the inability to obtain reliable geophysical information. However, the increased demand for petroleum products has promoted a renewal of activity. Several new oil and gas shows have been reported. A map, showing their location, is presented.

Magnetic and gravity instruments are considered unsuitable for exploration of the area except, perhaps, for indicating trends. The refraction seismic method was successful in discovering one structure which had a considerable amount of relief below the Pennsylvanian. This method is unsuitable for finding structures of low relief. The reflection seismic method is more successful here.

The air-shooting method developed by Poulter has provided good reflections. An air record is shown.

A recommendation is made that the Poulter method be employed using multiple geophones, variable patterns, variable charges, variable spacing, etc. in order to determine the technique best suited for each particular area.

SEISMIC — GENERAL

71. *Applied Geophysics in W. Germany during the Last Five Years.*
H. Closs, Proc. Third World Petr. Cong., 1951, Section 1, pp. 564-582.

General data are given regarding the recent development of the reflection seismic method. The relatively simple instruments of the first stage of development led to new types fitted out with two simultaneously acting gain controls together with an increase in the number of traces. Due to the improvement of the equipment the field technique underwent many valuably modifications by which new areas were opened up for the reflection seismic method. Some examples are given of modern surveys in the N. W. German salt stock area and some general conclusions drawn from the results. The conditions in the Emsland and in the foreland of the German Mittelgebirge, the youngest oilfield area of N. Germany, are outlined with respect to reflection seismic work. For the refraction seismic method particularly, experiences with blasting in deep boreholes are described. Concerning gravimetry and magnetics, recent experiences and ideas on regional anomalies are given.

72. *Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain,* Pt. 5: *Woods Hole, New York and Cape May Sections.*
M. Ewing, J. L. Worzel, N. C. Steenland & F. Press, Geophysics, Vol. 16, No. 2, pp. 286-288, April, 1951.

Dr. Ewing and his associates have pioneered in the application of the refraction seismograph to the study of submarine geology. In this paper, the latest of a series of reports, the first of which appeared in 1937, results are given of shooting on three lines or sections across the continental shelf. The sections extend south from Woods Hole, Mass., southeast from Fire Island, New York, and southeast from Cape May, New Jersey. The latter is an extension of a section previously shot across the coastal plain in New Jersey.

73. *Seismic Surveys over Asymmetrical Structures in S.W. Persia.*
D. T. Germain-Jones, Proc. Third World Petr. Cong., 1951, Section 1, pp. 546-563.

A description is given of the type of structures which form the targets of seismic work in S.W. Persia. The difficulties encountered in their location and definition are considered, and brief details of the refraction technique developed for this large scale problem are given. A need has arisen for more accurate delineation of these structures, particularly of the steeper flanks, and this has led to an examination of the possibility of improving the interpretation technique. Examples of the results obtained over theoretical structures are given.

Seismic work in the plains area has shown marked discrepancies between the results of refraction and reflection surveys in the definition of the axes. Tentative explanations for these discrepancies are submitted.

SEISMIC — INTERPRETATION

74. *Seismic Velocity as a Function of Depth and Geologic Time.*
L. Y. Faust, Geophysics, Vol. 16, No. 2, April, 1951.

Velocity data are compiled from measurements of nearly 1,000,000 ft. of section in 500 well surveys in the U.S. and Canada. Average velocities for shale and sandstone sections are arranged by depth and geologic age. Deviations from the mean values are attributed to lithologic variations. The variations of velocity with depth and time are studied independently in order to develop a quantitative relationship. It is concluded that the velocity for an average shale and sand section is given by the equation:

$$V = 125.3(ZT)^{1/6}$$

where V is the velocity in ft./sec., Z is the depth in ft., and T is the age in years. Velocities in limestone show less definite evidence of increase with age and depth.

75. *Velocity Information needed for Seismic Interpretation.*
J. W. Daly, World Oil, Vol. 132, No. 7, pp. 86-88, June, 1951.

More extensive velocity information is essential in connection with seismograph work. Better velocity control is needed to assure correct interpretations and to obtain maximum return for sums spent on seismograph work. Although velocity surveys are expensive their cost is minor in relation to the total cost of a seismograph programme.

76. *Seismic Record Sections.*
H. R. Prescott, Geophysics, Vol. 16, No. 4, pp. 613-625, October, 1951.

A method is described whereby seismic records may be secured which have sufficient dimensional stability that a composite reprint of several records, from a continuous profile, when placed in proper sequence, yields a cross-section of seismic arrivals. A method is described for entering corrected time scale on the seismic record section itself. Double recording is provided, with traces in transposed positions but alike in phase relation, which makes possible the construction of closed traverse sections. A few examples of the record section are shown and some uses suggested.

77. *The Theoretical Determination of the Travel Time.*
J. Kilezer, Geofis. Pura e Appl., Vol. 19, Fasc. 3-4, pp. 144-155, 1951.

After a short introduction in which the propagation of waves in an elastic medium, the formation of wave fronts, and the determination of trajectories are discussed in accordance with the Huygens principle the travel time of a wave spreading from the point P_1 to P_2 over a path 'S' is defined as the integral

$$\int_{P_1}^{P_2} \frac{dS}{V},$$

where 'v' is the velocity of propagation. The simplifying assumption is made that the waves are plane, which removes the source of the disturbance to infinity, but does not change the direction of the trajectory. The method is applied to two parallel strata, two oblique strata, and to four strata. The derived formulae are applicable with slight changes to reflected and refracted waves.

78. *Deep Basement Reflections in Big Horn County, Montana,*
A. Junger, Geophysics, Vol. 16, No. 1, pp. 499-505, January, 1951.

During a seismic survey in Big Horn County, Montana, a number of deep reflections from 7.0 to 8.5 seconds were observed. The reflecting surfaces are relatively flat as shown by the small stepouts. It is demonstrated that these reflections cannot be multiples and that they therefore must come from inside the basement at depth of 18-21 km. The nature of the reflecting surfaces cannot be determined from available data, but it is pointed out that they fall in the depth range generally stated for the depth of the granite layer.

SEISMIC — THEORY & RESEARCH

79. *A Seismic Research Laboratory on Wheels.*
W. E. Pugh, Petr. Eng., Vol. 23, No. 11, pp. B 78-B 82, October, 1951.

A laboratory on wheels is the latest tool to be used for more accurate and efficient seismic exploration, now being provided by the S.S.C. for the various oil companies and their exploration divisions. In essence, this tool consists of regular and special seismic recording equipment for a pilot crew to operate in new or extremely difficult shooting areas, and also to conduct normal field tests to carry out 'trouble shooting' in areas where a regular crew is already operating. Its primary purpose, however, is the former; that is, the determination of the proper instrumentation and field procedure before a regular crew enters a new or difficult area.

80. *A new Approach to the Study of Elastic Propagation in Rocks.*
F. F. Evison, Mon. Not. Roy. Astr. Soc., Geophys. Suppl., Vol. 6, No. 4, pp. 209-221, November, 1951.

Seismology and seismic prospecting have developed techniques for observing the paths taken by elastic energy generated in the ground, but are handicapped from studying other aspects of propagation. An electromechanical vibrator has been designed to assist a more general study, especially of phenomena involving amplitude and frequency. Experiments have been carried out in mines, with the vibrator radiating energy at frequencies from 300 c/s. to 1,000 c/s., either continuously or in the form of a pulse. Vibrations were recorded at distances up to 550 ft. In sandstone, the attenuating effect of fissures was studied in detail. In chalk, time-distance relations were obtained which gave stratigraphic indications in good agreement with the known geology, and a steeply dipping shattered zone was discovered. Frictional attentuation in the chalk at the frequency 600 c/s. was found to be 1.5 db./100 ft. for compressional waves of velocity 7.66 ft./msec., and 1.8 db./100 ft. for shear waves of velocity 4.08 ft./msec. Variations in the energy reflected from a horizontal interface at various angles of incidence are briefly discussed with reference to published theoretical tables. The experiments suggest a new line of approach to problems of both theoretical and practical interest.

81. *Rayleigh Waves from Small Explosions.*
M. B. Dobrin, R. F. Simon & P. L. Lawrence, Trans. Am. Geophys. Un., Vol. 32, No. 6, pp. 822-832, December, 1951.

As part of a programme to study ground disturbances that interfere with seismic prospecting, an experimental seismic crew of the Magnolia Petroleum Co. has been investigating Rayleigh Waves from shot-hole explosions at distances up to about 3,000 ft. Waves have been recorded by vertical and horizontal geophones through a system giving flat response between 5 and 200 cycles/sec. The geophones have been disposed along surface profiles with separations that are short compared with Rayleigh wavelengths and also at various depths up to 100 ft. in boreholes. Rayleigh waves from air explosions have also been recorded.

Sample arrays of records are presented on which individual waves from hole and air shots can be followed for horizontal distances up to about ten wavelengths. Dispersion characteristics observed on the records are plotted in a form permitting comparison with theoretical dispersion curves for various kinds of surface layering. Effects of varying the depth of the explosion are observed and compared with theoretical predictions. Particle-motion trajectories are plotted both at the surface and at various depths. Results all show as good agreement with classical theory as can be expected in view of the simplifying assumptions that must be made in deriving this theory.

Constant-frequency wave trains were observed immediately after the airwave arrival on the records made from single air explosions eight feet above the ground. These are shown to be waves of the type predicted by the Press-Ewing theory of surface wave coupling to the atmosphere. (See Abstract No. 26).

82. *A Seismic Wave Guide Phenomenon.*
K. E. Burg, M. Ewing, F. Press & E. J. Stulken, Geophysics, Vol. 16, No. 4, pp. 594-612, October, 1951.

On one particular prospect in shallow water repetitive patterns appeared in short spread seismograms in such prevalence as to jeopardize identification of desired reflections. It is demonstrated that under favourable conditions, less restrictive than thought necessary heretofore, a layer of water comprises an effective wave guide for seismic energy propagation. Reinforcement fronts formed by reflection of multiple sound in water can develop into a set of waves completely overshadowing other seismic arrivals. With but minor modifications, conventional wave guide theory applies.

Examples from the prospect are presented to illustrate various reinforcement patterns. Observed frequency characteristics, group velocity, and phase velocity magnitudes are investigated for normal modes of propagation.

83. *Dispersion in Seismic Surface Waves.*
M. B. Dobrin, Geophysics, Vol. 16, No. 1, pp. 63-80, January, 1951.

A non-mathematical summary is presented of the published theories and observations on dispersion, i.e. variation of velocity with frequency, in surface waves from earthquakes and in water borne waves from shallow-water explosions. Two further instances are cited in which dispersion theory has been used in analysing seismic data.

In the seismic refraction survey of Bikini Atoll, information on the first 400 ft. of sediments below the lagoon bottom could not be obtained from the ground wave first arrival times because shot-detector distances were too great. Dispersion in the water waves, however, gave data on speed variations in the bottom sediments which made possible inferences on the recent geological history of the atoll.

Recent systematic observations on ground roll from explosions in shot holes have shown dispersion in the surface waves which is similar in many ways to that observed in Rayleigh waves from distant earthquakes. Additional experimental and theoretical study of this type of surface wave dispersion may provide useful information on the properties of the surface zone and add to our knowledge of the mechanism by which ground roll is generated in seismic shooting.

84. *Elastic Wave Velocities in Sedimentary Rocks.*

D. S. Hughes, & H. J. Jones, Am. Geophys. Union Trans., Vol. 32, No. 2, pp. 173-178, 1951

A group of 11 sedimentary rock samples has been studied using the method previously described of impressing a series of pulses on the specimen. Measurements were made in the range of 0-1,100 kg/cm^2 and 25-175 C. One limestone and one dolomite sample have also been measured up to 200 kg/cm^2. Results are shown on small diagrams, and variations of velocities and elastic moduli with depth are computed assuming a temperature gradient of 9,5 C. per 1,000 ft. of depth. Vertical-well velocity surveys from the wells, from which the samples were taken, give values which are consistently somewhat higher than the laboratory values.

85. *Some Relations among Sedimentation, Stratigraphy and Seismic Exploration.*

W. C. Krumbein, Am. Assoc. Petr. Geol. Bull., Vol. 35, No. 7, pp. 1505-1522, 1951.

This is the 24th annual address of the President of the Society of Economic Paleontologists and Mineralogists. The relations between seismic velocity data and conventional sedimentary-stratigraphic principles are reviewed. Investigations of velocity variations and the sedimentary factors which control them and the extension of a real analysis to include patterns of rock density, elasticity, and other physical properties should be of fundamental importance to both geologists and geophysicists.

86. *On the Relationship between Seismic Amplitude and Charge of Explosive Fired in Routine Blasting Operations.*

G. M. Habberjam & J. T. Whetton, Geophysics, Vol. 17, No. 1, pp. 116-128, January, 1952.

An account is given of an investigation into the relationship between charge of explosive fired and seismic amplitude in routine quarry blasting. By keeping the instrument fixed over the investigation and by choosing a suitable recording position the effects of site factor can be considered to have been reduced to a practical minimum.

The observations, which were made at distances of approximately 400 ft., give a relation between first peak amplitude and charge of the type.

$$C = Q.A^{1.242}$$

where the factor 'Q' varied between 1 and 3 approximately and would apparently be assignable to varying blasting conditions.

The results have also been reviewed in the light of an amplitude square relation modified on the supposition that the energy loss involved in practical blasting is a function of the charge.

GRAVITY — INTERPRETATION

87. *Regional Correction of Gravity Data.*

R. Vajk, Geofis, Pura e Appl., Vol. 19, Fasc. 3-4, pp. 129-143, 1951.

A brief history of existing methods for the removal of regional gradients from geophysical maps is discussed. These include mechanical mathematical methods, such as those used in the construction of residual and second vertical derivative maps, and graphical methods, such as the smoothing of profiles. It is concluded that both methods may give erroneous results unless the maps are analysed properly. Mathematical methods such as the averaging processing employed in residual maps cannot completely eliminate the effect of residual anomalies nor do they give correct fault indications. The method of graphically smoothing gravity and magnetic profiles is described as being entirely too arbitrary. For some cases, a graphical method is described as an alternative that, in Vajk's opinion, more correctly describes the regional field. The advantage of the method and illustrations of its use are presented.

88. *The Relationship between the Local Anticlines and Gravity Anomalies in the Russian Platform (in Russian).*

A. T. Donabedov & A. Meshcheriakov, Akad. Nauk S.S.S.R. Doklady, Tom 79, No. 3, pp. 503-506, 1951.

Most anticlines in European U.S.S.R. may be characterised by either positive or negative gravity anomalies over the crest, while a few show neither maxima nor minima but a pronounced zone of higher gravity gradients. The inconsistency of gravimetric evidence makes geologic interpretation difficult and often leads to erroneous conclusions in oil and mineral exploration. By constructing a geologic map of the most important anticlines separated according to gravimetric characteristics, the observed differences may be shown to result from differences in the deep geology of various regions, such as the elevation or subsidence of ancient rocks.

89. *Least Squares Residual Anomaly Determination.*

W. B. Agocs, Geophysics, Vol. 16, No. 1, pp. 688-696, January, 1951.

The residual anomaly is defined as the deviation from the mean anomaly surface, or the regional surface. The regional surface which best fits the observed anomaly data may be determined by least squares. For the case of the simple plane, the equation of the regional would be $Z = Ax + By + C$, and the residual anomaly would be $R = G - Z = G - (Ax + By + C)$, where G is the observed value at the station whose co-ordinates are x, y. The constants of the equation of the regional may be determined by using the normalizing equations:

$$\Sigma\, R\partial R/\partial A = 0; \quad \Sigma\, R\partial R/\partial B = 0; \quad \Sigma\, R\partial R/\partial C = 0.$$

It is shown that for a symmetrical distribution of observational points about a centre, the regional value at the centre would be equal to $\sum_{1}^{n} Gn/n$ and this value subtracted from the central point is the residual. Given the coordinates and the observed values, the regional may be determined, and the residual for the area calculated rapidly. An example is given of the procedure.

90. *Graphical Evaluation of the Anomalies of Gravity and of the Magnetic Field, Caused by Three-Dimensional Bodies.*

F. Gassmann, Proc. Third World Petroleum Congress, 1951, Sec. 1, pp. 613-623.

If anomalies of gravity or of the terrestrial magnetic field are to be interpreted, methods are required which enable us to evaluate the gravitational or the magnetic field of bodies of any given shape quickly. Since limited accuracy is sufficient, graphical methods are suitable. This paper deals with such graphical methods. Its consists in carrying out the required triple integrations in two steps, the first being a simple, the second a double integration. By the aid of graphs the integrations are reduced to simple counting.

GRAVITY — THEORY & RESEARCH

91. *Tidal Variations of Gravity.*
M. S. Reford, Trans. Am. Geophys. Un., Vol. 32, No. 2, pp. 151-156, April, 1951.

The changes in the value of gravity at Toronto with respect to time have been observed with a North American Gravimeter. Readings were taken every quarter of an hour over a period of 29 days, partly by normal visual methods and partly by photographic recording. A drift curve for the instrument has been calculated and the residual fluctuations analysed harmonically. The results yield the amplitudes and phases of the changes in gravity corresponding to the tidal constituents M_2, S_2, N_2, K_1 and O_1. The amplitudes of these constituents have been compared with the tide-generating potentials of the Sun and Moon to give the function of Love's numbers $m = 1 + h - 3k/2$. The analysis of the records for 29 days gives a mean value of m equal to 1.0(9) for the semi-diurnal and 1.0(0) for the diurnal constituents. A separate analysis of the records for the first 15 days, which were taken by the more accurate visual method, gives $m = 1.2(2)$ and 1.0(2) for the semi-diurnal and diurnal constituents respectively. These results agree with those obtained by other methods of studying earth tides.

92. *Gravity Exploration for Reefs and other Porosity Maxima.*
H. Klaus & J. C. Hughes, World Oil, Vol. 132, No. 7, pp. 78-84, June, 1951.

Gravity work can play an important role in exploration for porosity maxima, including reefs, sand lenses, shoe string sands, etc. Variations in porosity bear a definite and decisive relationship to the bulky density of rocks. While attention has been focussed on reefs through spectacular Canadian and West Texas discoveries, other types of porosity maxima may again be of great importance.

93. *Tide-Producing Forces and Artesian Pressures.*
W. O. George & F. E. Romberg, Am. Geophys. Un. Trans., Vol. 32, No. 3, pp. 369-371, 1951.

Simultaneous observations of gravity, atmospheric pressure, and artesian pressure were made during a 48 hour period, Nov. 30th to Dec. 2nd, 1949 at the M. R. Gonzales artesian water well about one mile south of Fort Stockton, Pecos County, Texas. The well is about 700 km. from the gulf coast and more than 1,300 km. from the Pacific coast at the nearest points. The curve of observed gravity conforms to that of the computed tide-producing force (except at the beginning, which may be the result of instrumental error) in time and relative amplitude of maxima and minima. Variations in the observed force are approx. 25% greater than in the computed curve for which a rigid earth is assumed. The curve of artesian pressure also corresponds to the curve of the computed tide-producing force. The curve of atmospheric pressure conforms less closely, suggesting fluctuation in atmospheric pressure may be less important than the earth tide in causing diurnal fluctuation of water level.

MAGNETIC — GENERAL

94. *Alberta Flying Magnetometer Survey Completed.*
T. M. O'Malley, World Oil, Vol. 132, No. 6, pp. 235-237, May, 1951.

An airborne magnetometer survey of the Peace River area in N.W. Canada, financed by the following four oil companies: Socony Vaccuum Exploration Co., Stanolind Oil & Gas Co., Imperial Oil Co. Ltd., and Canadian Gulf Oil Co.

The survey was executed by Canadian Aero Service Ltd. at a cost of approximately $ 150,000. It began in late May, 1950, and was completed in late August of the same year.

Reasons for the survey, methods used, and the results obtained are described.

95. *Aerial Magnetic Discoveries.*
W. P. Jenny, World Oil, Vol. 133, No. 6, pp. 85-92, November 1951.

Described are some results of an aerial magnetic survey over a portion of the serpentine district of South Central Texas. Several local anomalies were selected from among the many indicated by the survey for further study and possible drilling. Ground micro-magnetic work very closely confirmed, and further detailed the pictures obtained, in the rapid air work. When these several areas were drilled, each was proved productive by the first well drilled.

96. *Airborne Magnetometer.*
T. M. O'Malley, Eng. J., Vol. 34, No. 3, pp. 177-179, 1951.

The airborne magnetometer, first developed as a submarine detector, was modified for geophysical use and first flown in 1941. The geophysical equipment consists of a continuously recording magnetometer, a stabilized continuous strip camera, and a recording ratio altimeter. Parallel traverses are flown at an altitude of 500 feet and the three records obtained are worked and numbered simultaneously. Aerial photographs are used for flight guidance but Shoran is used under some circumstances. A series of overlapping closed loops and tie lines are flown as survey base lines so that no measurement is more than 1½ minutes from a control point. Diurnal variation is measured on the ground while surveys are being made and flights are cancelled if the variation is large. The location coordinating works are plotted from strip film, to photographs, to base maps, and values scaled from the magnetic profiles are contoured. Surveys have been made to search for magnetic ores, nonmagnetic ores in magnetic host rock, and to solve structural problems including dykes, intrusions, faults and folds. A byproduct of the surveys is the incidental aerial photographs which may be taken and used to prepare topographic maps and controlled mosaics for subsequent ground exploration surveys and photogeologic interpretations.

97. *Aerial Exploration.*
H. Jenson, Min. Cong. J., Vol. 37, No. 2, pp. 106-107, 1951.

The advantages, limitations, and special applications of the airborne magnetometer are discussed. Advantages noted are great sensitivity (a recent magnetic map was made with a 1-gamma contour interval); reliability (surveys have been made involving 60 consecutive days of flight operation and 10,000 traverse miles per month); cost ranges from $ 7—$ 25 per linear mile of traverse; instrument gives a continuous record, rapid response, and is drift free; the survey is conclusive; "the whole answer is achieved in one operation." Limitations due to the generalization of information resulting from elevation are partially compensated by flying at an altitude of 500 feet. This altitude effect aids in showing a truer location of a large ore body than does data taken at the surface. Aeromagnetic surveys for ores are most economically applied when a susceptibility difference exists between the ore and surrounding rock. High precision aeromagnetic maps aid in solving structural problems and will show dykes, intrusions, faults and folds. More than 5 million square miles have been surveyed in four years of commercial operation.

98. *A Magnetic Survey of Adams County, Ohio, Crypto-Volcanic Structure.*
L. W. Sappenfield, The Compass, Vol. 28, No. 2, pp. 115-123, 1951.

A magnetic survey of an area of about 150 square miles in Adams, Highland and

Pike Counties, Ohio, shows two anomalies of 800 and 900 gammas separated by 300-400 gamma saddle. The lower anomaly crosses a crypto-volcanic structure mapped by Bucher. Analysis of the magnetic data gives a depth to the surface of the basement of 6,000-6,500 ft. It is postulated that the anomaly is produced by an intrusion of basic magma into the siliceous basement rocks and that the cryptovolcanic structure has been formed by the accumulation of gas or water vapour escaping from the intrusive.

99. *A Two-Level Aeromagnetic Profile across Western Texas.*
H. W. Hoylman, World Oil, Vol. 132, No. 2, pp. 62-64, 1951.

Fairchild Surveys made a two-level reconnaissance flight southeast from El Paso to Sanderson, Tex., a distance of 300 miles. The flight levels were 8,000 and 12,0co feet above sea level. A figure shows the two aeromagnetic curves with regional gradient removed, topography and surface geology. Fifteen specific anomalies along the profile are discussed to demonstrate the greater detail in interpretation possibe with two-level surveys.

MAGNETIC — INSTRUMENTAL

100. *The Torsionally Suspended Magnetic Needle.*
O. Meisser, Geofis. Pura e Appl., Vol. 19, Fasc. 1-2, pp. 60-74, 1951.

A comparison is made of the functioning of a magnetic needle supported on a jewel bearing and a needle suspended between two torsionally strained wires. The frictional moment and the limit of sensitivity are computed for both forms of suspension, and in all respects the first design is inferior. Another advantage of the latter design is the possibility of constructing zero reading instruments. The method of adjustment using permanent magnets or Helmholz coil is described. The period of natural oscillation of such a needle is determined assuming the torsion wire to be composed of different materials such as quartz, brass, steel, tantalum, or tungsten. An extended discussion of the magnetic moments and other characteristics of permanent magnetic materials to be used as auxiliary deflection magnets is included. The computed characteristics for various shapes and materials of the magnets are given in graphs, optimum parameters for the design of these instruments are determined, and their calibration discussed.

101. *Magnetic Prospecting Instruments.*
O. Meisser & H. Jung, Geofis., Pura e Appl., Vol. 19, Fasc. 1-2, pp. 75-91, 1951.

An accuracy of 0.1 % is sufficient in magnetic instruments used by exploration geologists and mining engineers. The sensitivity of such an instrument makes it possible to neglect diurnal variation and still be adequate for localization of disturbing magnetic masses. A new type of universal magnetometer has been developed, using a torsionally supported magnetic needle, as suggested by Meisser. It is built as a zero indicating instrument; the compensating magnetic field is produced by auxiliary magnets, formed of special alloys, characterized by high stability of magnetic properties and low temperature coefficient. To make possible use of the same needle, oscillating horizontally, for measurement of both the horizontal and the vertical components of geomagnetic field, special deflectors are employed, as suggested by Lamont. The vertical component 'Z' induces in the deflectors magnetic moments proportional with the intensity of 'Z'. Therefore the deflection of the needle again measures its intensity with a new calibration constant. A detailed discussion of the functioning of deflectors is presented with several graphs and tables and the construction of the instrument is described in detail.

102. *Patents.* Abstracts in Geophysics, Vol. XVII, No. 1, p. 139, January, 1952.

U.S. Re. 23,397 (Original No. 2, 468,968). 7th Aug. 51. A total field magnetometer.

U.S. 2,559,586. 10 July, 1951. An airborne magnetic variometer.

U.S. 2,560,132, 10 July, 51. A two-element flux-valve type of magnetometer.

U.S. 2,562,120. 24 July, 51. Magnetometer utilising the Hall effect.

U.S. 2,564,854. 21 Aug., 51. Flux-valve magnetometer which can be oriented by special control of servomotors.

U.S. 2,565,799. 28 Aug., 51. Flux-valve magnetometer utilising special electronic form of registration.

ELECTRICAL

103. *The Value of Geoelectrical Investigations in Exploration and Discovery of Ore Deposits.*

O. Keunecke, Zeitschr. Erzbergbau u. Metallhüttenwesen, Band 4, Heft 7, pp. 257-265, and Heft 8, pp. 307-318, 1951.

Electrical methods are usually used in prospecting for nonferrous deposits because of the greater electrical conductivity of many sulphide ores. One difficulty results from the fact that porous strata, containing water, may have even greater conductivity than ores. The electromagnetic induction procedure is believed to be the best method, especially the modification of the original Elbof method. A horizontal circular emitter of rubber-insulated cable forms a coil 20 to 30 meters in diameter through which alternating current of about 500 cycle per sec. is pulsating. The power used may be as much as 1 or 2 kw. The coil is placed horizontally on the ground, inducing in it an alternating ellipticaliy-polarized electromagnetic field. The intensity of this field is measured along radial profiles for distances of 800 to 1,000 meters. From the field pattern, it is possible to detect anomalies caused by underground deposits. The depth of penetration may be as much as 500 meters. Several examples from different countries are included, as well as directions on the best use of the method and the interpretation of measurements.

104. *Nonpolarizable Diffusion Electrodes.*

S. Turlygin & N. A. Karelina, Akad. Nauk S.S.S.R., Doklady, Tom 79, No. 6, pp. 965-968, 1951.

In studying telluric currents under different conditions, the authors experienced difficulties with existing types of nonpolarizable electrodes, especially when using them in sea water, and have worked out a new design. In these the use of protective films was eliminated, as eventual source of unstable electrical dipoles. The new electrode is designed as a reversible system, the metallic terminal of the electrode being protected against contact with the ions of other metals by a solution of its own salt, covered with a substantial layer of a gel, again containing the same salt in the same concentration, and thus made conductive. One of the possible realizations of this principle consists of a zinc rod passing through a rubber stopper and immersed at its extremity in a solution of $ZnSO_4$ contained in a long tube with corrugated walls; the end section of the tube is filled with agar-agar in which $ZnSO_4$ is dissolved. Two such electrodes were tested during six months in the field work. The potential drop across such electrodes is less than 0.1 millivolt at the temperature near the freezing. A disadvantage is the variation of potential with temperature.

105. *Geophysics on the Pennsylvania Turnpike.*

H. L. Scharon & A. B. Cleaves, Min. Eng., Vol. 3, No. 4, pp. 351-355, 1951.

Electrical resistivity surveys were made to determine depth of bedrock at 245 proposed cuts and sites of structures along the Philadelphia and western extensions.

of the Pennsylvania Turnpike. Selected examples are discussed to show the different geologic conditions found, including areas of Limestone outcrops and sinkholes, Triassic shales and sandstones, a Triassic diabase sill, nearly horizontal Pennsylvanian shales, and recent gravels over Pennsylvanian shales. Accuracy in determining overburden thickness, as demonstrated in 104 cut sections, is said to be less than 2 feet.

106. *An Electromagnetic Interpretation Problem in Geophysics.*
L. B. Slichter, Geophysics, Vol. 16, No. 3, pp. 431-449, July, 1951.

An interpretation problem in electromagnetic prospecting is discussed. A flat earth in which the three electrical properties of material vary only with depth is subjected to an alternating inducing field produced by a dipole above the surface with axis perpendicular to the surface. Observations of the horizontal or of the vertical component of the magnetic intensity at the ground's surface are supposed to be available at all distances. From these observations solutions for the three unknown functions are developed. When the magnetic permeability is variable, the solutions for the permeability and dielectric functions require observations at two different frequencies. The conductivity function may be found from observations at a single frequency.

It is shown that the horizontal and vertical components of the magnetic field intensity are mutually dependent in the region above the ground's surface, and formulae independent of the ground's characteristics are deduced for expressing Hp(p, Zi) in terms of Hx(p, Zi), and vice versa. Here $Z = Zi \leqq h$ denotes a plane coincident with or above and parallel to the earth's surface.

107. *A Conducting Sphere in a Time Varying Magnetic Field.*
J. R. Wait, Geophysics, Vol. 16, No. 4, pp. 666-672, October, 1951.

The secondary magnetic fields are evaluated for the case of a conducting sphere in a relatively poor conducting medium under the influence of a time-varying magnetic field. The sinusoidal and step function responses are both considered. The responses so calculated are thought to be useful in a geophysical prospecting method which utilizes the transient behaviour of induced eddy currents in a highly conducting ore zone.

108. *Subsurface Earth Exploration by Electrical Resistivity Method.*
L. C. Pendley, Kentucky Acad. Sci. Trans., Vol. 13, No. 3, pp. 189-200, 1951.

A brief description of the electrical-resistivity method for subsurface reconnaissance is given, primarily for the needs of civil engineers. Examples of resistivity curves, along with the evidence obtained from drill cores at the same sites are presented.

It is concluded that by using this method, in conjunction with some properly located drill holes, it is possible to map the subsurface conditions of large areas at a saving of both time and money; that the depth to bedrock can be determined with sufficient accuracy for general highway work; and that the amount of moisture present is the major factor in determining resistivity.

109. *Geophysical Survey of the Blantyre-Limbe Area.*
H. W. Ball & M. S. Garson, Nyasaland Geol. Survey Ann. Rept. 1950, p. 10, 1951.

An isoresistivity map of the area north of Blantyre and Limbe has been made on the basis of east-west resistivity traverses at 2,000 ft. intervals. The area consists of granulitic gneisses and some biotite schist with syenite intrusions, and water supplies are found chiefly in shear zones in the syenite. In general, the schists had lower resistivity values than syenite or syenite gneiss. Most values lie between 10,000 and 40,000 ohm/cm. with good waterbearing zones below 10,000 and massive syenite above 50,000 ohm/cm. Below the weathered zone, the value of fresh syenite was over 300,000 ohm/cm. Aquifers were located by depth probes and the results found to be reasonably accurate.

110. *A Preliminary Report on the Electrical Resistivity Survey at Medicine Lake, Montana.* G. J. Edwards, U.S. Geol. Survey Circular 97, p. 16, 1951.

Resistivity measurements, using the depth profiling method, were made in the vicinity of Medicine Lake, northeastern Montana, to determine depths to the Fort Union formation and the existence of a buried channel. Electrical characteristics of the Fort Union were found to range from 800 ohm/cm. in a lignite seam to 5,430 ohm/cm. in a sandy clay and gravel below the lignite. Altitudes of the Fort Union, based on interpretations of the apparent resistivity curves, are shown on a contour map and profiles. The map shows a channel extending eastward under Medicine Lake and then turning and continuing to the northeast.

ERRATA

A. T. DENNISON—THE DESIGN OF ELECTROMAGNETIC GEOPHONES

(Geophysical Prospecting, Vol. 1, No. 1)

Fig. 2b, page 6 was interchanged with fig. 6b, page 19.

Page 6, right hand side of last equation:

$$\text{reads: } \frac{K}{M}\frac{d^3x}{dt^3} \quad \text{should read: } \frac{K}{L}\frac{d^3x}{dt^3}$$

A STUDY OF WELL VELOCITY DATA IN NORTH WEST GERMANY *

BY

W. VON ZUR MÜHLEN ** and G. TUCHEL ***

Abstract

The article is based on data from 74 seismic well velocity surveys in N.W. Germany. The effect of overburden is illustrated by means of diagrams representing interval velocities against depth. To eliminate observational errors and lithological variations from well to well, interval velocities from about the same depth are averaged. Thus, relatively uniform curves are obtained for lower Tertiary, Upper Cretaceous, and Lower Cretaceous (Albian), making the effect of overburden better evident than from individual observations. The vertical gradient of velocity for these geological sections are given. Furthermore, they are compared with curves for Lower Tertiary and Cretaceous obtained in N. America. Due to its high lime content, the Upper Cretaceous of N.W. Germany has a much higher velocity than that observed in the Cretaceous of N. America. The curves for shales of the Lower Tertiary and Lower Cretaceous (Albian), however, are similar in both countries. In older formations, on the other hand, e.g. Jurassic and Triassic, lithologic character has the dominant influence and the effect of overburden is rather small and often scarcely noticeable.

The data considered cover a depth range down to 2,700 meters. The interval velocities are generally based on the use of various equal intervals.

Introduction

In the whole area of the present German Confederation, 78 well velocity surveys were carried out from 1934 to 1952, of which 74, measured in North West Germany, have been considered in this paper. The surveys were made on behalf of the interested oil companies, chiefly by the contractors Prakla and Seismos, but also by some of the oil companies themselves, like Deutsche Vacuum Öl AG, Gewerkschaft Brigitta and Gewerkschaft Elwerath, all of them applying Schlumberger cable, and using geophones and other measuring equipment of their own design, as Deutsche Vacuum Öl AG, Prakla and Seismos. Appreciation is due to the following oil companies for providing data: C. Deilmann Bergbau GMBH, Deutsche Erdöl AG, Deutsche Schachtbau und Tiefbohr GMBH, Deutsche Vacuum Öl AG, Gewerkschaft Brigitta, Gewerkschaft Elwerath, Preussische Bergwerks- u. Hütten AG, Wintershall AG.

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* Presented at the Hannover Meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

** Amt für Bodenforschung, Hannover.

*** Consulting Geophysicist, Hannover-Kirchrode.

A great deal of the well surveying was done on the initiative of Brinkmeier (Gewerkschaft Elwerath) and Haarstick (Deutsche Vacuum Öl AG).

The study reported here was suggested by the Amt für Bodenforschung (Geological Survey) in the course of a compilation and comprehensive review of the data available. Appreciation is expressed to Seismos GMBH Hannover, for valuable help. Some earlier work on the evaluation of well velocity data (not published) was done by Haarstick, Sander and Weigel.

GENERAL CONSIDERATIONS

The original purpose of seismic measurements in wells was to obtain time data for plotting reflections. However, from the beginning, these well surveys had also to their object the determination of interval velocities and of velocities in distinct stratigraphic components. It cannot be denied that some difficulties arose in exact picking out the arrivals on the record to warrant reliable results as required in the consideration of interval velocities. The error is generally confined to depths down to the top-layers of Upper Cretaceous, or to beds of higher velocity respectively. There are still other inaccuracies involved in the determination of interval velocities. All these errors are termed "observational errors". No effect of importance is to be expected from neglect of curved path for measurements at shallower depths, since the distance between shotpoints and wells in most cases is close to 100 metres, not exceeding 200 metres.

The location of the surveyed wells is shown in Fig. 1. As may be observed, the measurements are concentrated on wells in the oil fields, e.g. Emsland, Aller valley, Lüneburg and Lower Elbe areas. There are, however, velocity data from wells scattered widely over the intermediate area.

Comparing the velocity data from constant intervals and from identical geological sections naturally leads to the following questions:

1. Is there any relation between the pressure of overburden and the increase in velocity with depth?
2. Is there any regional relation between the velocities from identical stratigraphic component?

These problems have been treated by B. B. Weatherby and L. Y. Faust [1], N. A. Haskell [2], L. Y. Faust [3], and others with respect to conditions in North America. Whereas these authors were dealing mainly with sands and shales, calcareous beds play an important part in this paper. Although velocity determinations were made throughout the whole geological section from Upper Tertiary down to Carboniferous, the formations especially referred to in this paper concern:

1. Palaeocene and Lower Eocene;
2. Upper Cretaceous (Senonian, Emscher, Turonian and Cenomanian);
3. Lower Cretaceous (Albian).

All interval velocity data discussed in the following are given by diagrams in which the interval velocity is plotted against depth.

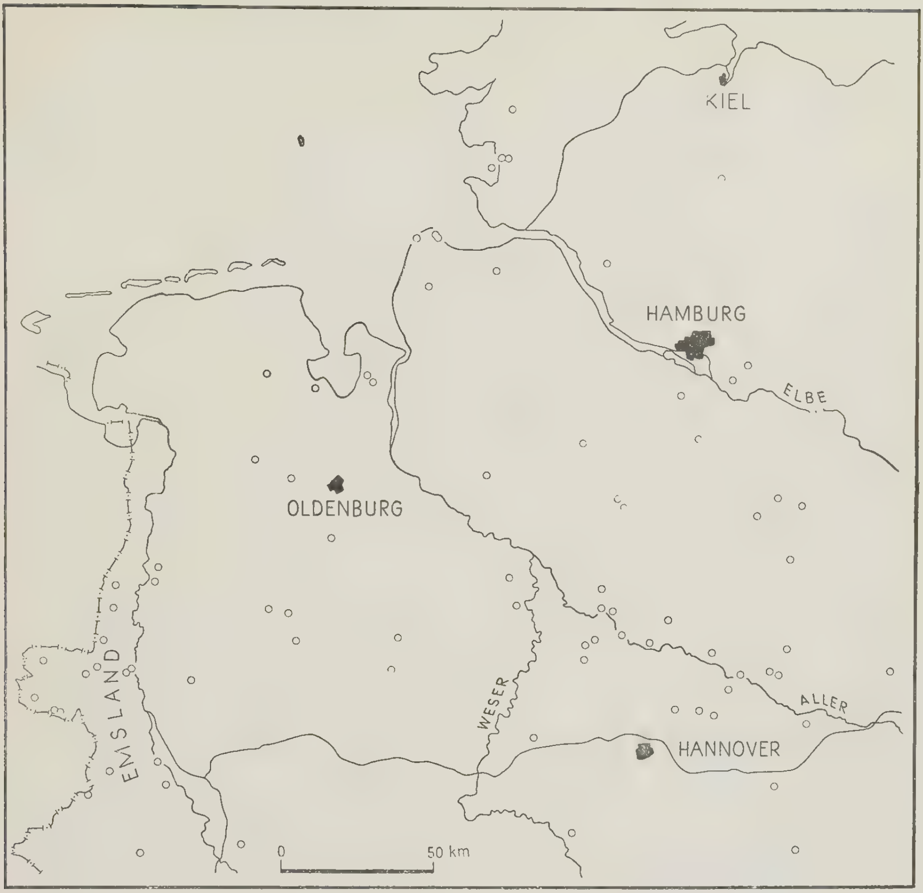

Fig. 1. Velocity Surveyed Wells in NW-Germany.

EXAMPLES OF INTERVAL VELOCITY VS. DEPTH AND DISCUSSIONS

Fig. 2 shows interval velocity vs. depth of a 200 m interval taken from the base of Tertiary upward in various wells. The interval comprises sediments of Palaeocene and Lower Eocene age and consists predominately of shales. The depth data relate to distances from the surface to the top of the interval. The increase of velocity with depth may be noticed from the arrangement of the individual points. On closer examination a more or less wide scattering of the points is to be recognised. As we are dealing with sediments of the same age and equal interval, the discrepancies can only be caused by lithologic variation and observational errors. In order to minimize the effect of these factors, the method of averaging velocity data from about the same depth range was applied. Thus, a generalized curve of mean velocity value is drawn for depths between 600 and 1100 metres. This curve shows a fairly linear increase of interval velocity with depth. The vertical gradient of interval velocity amounts to 0.63 metres/second per metre.

In Fig. 3, velocities of Senonian and Emscher Sections are plotted against depth. The vertical bars represent the thickness of the section. For comparison of the various data, the midpoint of the section is marked. It will be difficult to derive some sort of generalized curve from these points; a general tendency to increasing velocity with depth is, however, to be seen.

Further evidence of increase of interval-velocity with depth is produced by the following Figures 4 and 5, in which the velocity conditions of total Upper Cretaceous are represented in such a mode that the whole section is divided into intervals of 300 metres and 400 metres, respectively, with only one interval reaching from the base of Cenomanian upward and other intervals, the number of which depending on the thickness of Senonian and Emscher, being measured from the top layers of Senonian downward. There is an occasional overlapping of intervals due to less thicker Upper Cretaceous sections. But there is one thing common to all intervals, they are chiefly composed of calcareous sediments.

It is interesting to note that especially for greater depths the velocities of the upper part and the lower part of Upper Cretaceous have about the same values for the same range of depth. This may be explained by nearly the same lime content of the intervals concerned. The lime content of Cenomanian and Turonian as well as of the greater part of Senonian amounts to 75 to 90 %. Only a smaller section of Senonian has a lime content of 40 to 60%. The Cenomanian-Turonian velocities are marked by large circles in Fig. 4 and 5. Obviously both the velocities of Senonian and Emscher and Turonian-Cenomanian may be lined up to one zone clearly indicating an increase of velocity with depth, except the data close to the origin of the graph, where a rather wide scattering is to be seen. The generalised curve thus obtained from intervals of 400 metres of Upper Cretaceous age is shown in Fig. 6. The vertical gradient of velocity for a depth range from about 800 to 2000 metres amounts to 1.45 metres/second per metre.

Analysing the velocities measured at shallower depths, say down to 800 metres, it is found that the velocities observed in wells of the Emsland, of the sea coast area and Lower Elbe River area, including Sleswick-Holstein, are relatively lower than those observed in wells further to the East. This led to the attempt to determine two velocity vs. depth curves, as shown in Fig. 7. Of course these curves are approaching each other with increasing depth. Further there is a distinct change in the rate of increase of velocity in these curves.

A close relationship between velocity and depth of geologic section is shown by Fig. 8, in which Albian, a component of Lower Cretaceous, is represented. In this case, a rather uniform lithologic section, consisting predominantly of shales, is chosen. Leaving out the few scattered points in the initial part of the graph, the other points fit the curve of mean velocity satisfactorily. It has to be mentioned that velocities were taken from intervals, ranging from

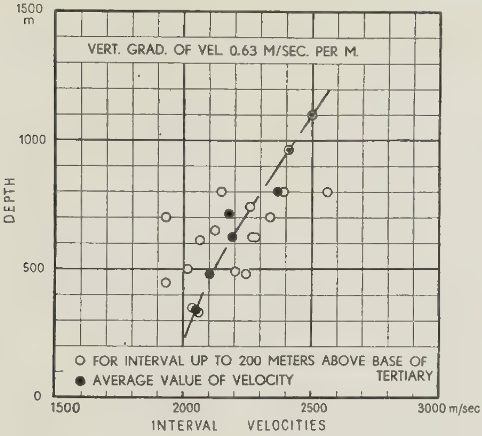

Fig. 2. Tertiary (Paleocene + Lower Eocene).

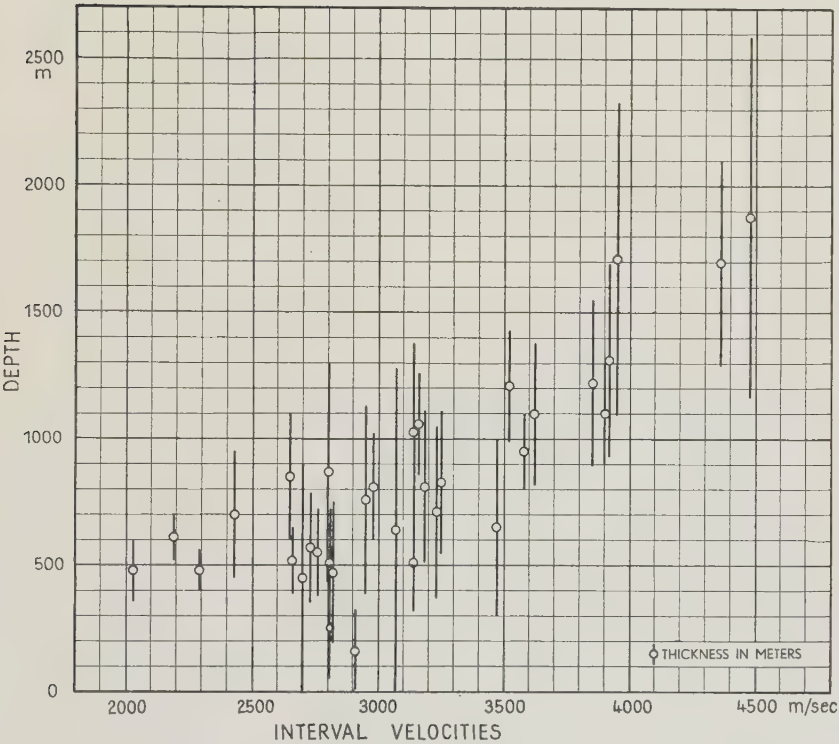

Fig. 3. Upper Cretaceous (Senonian + Emscher).

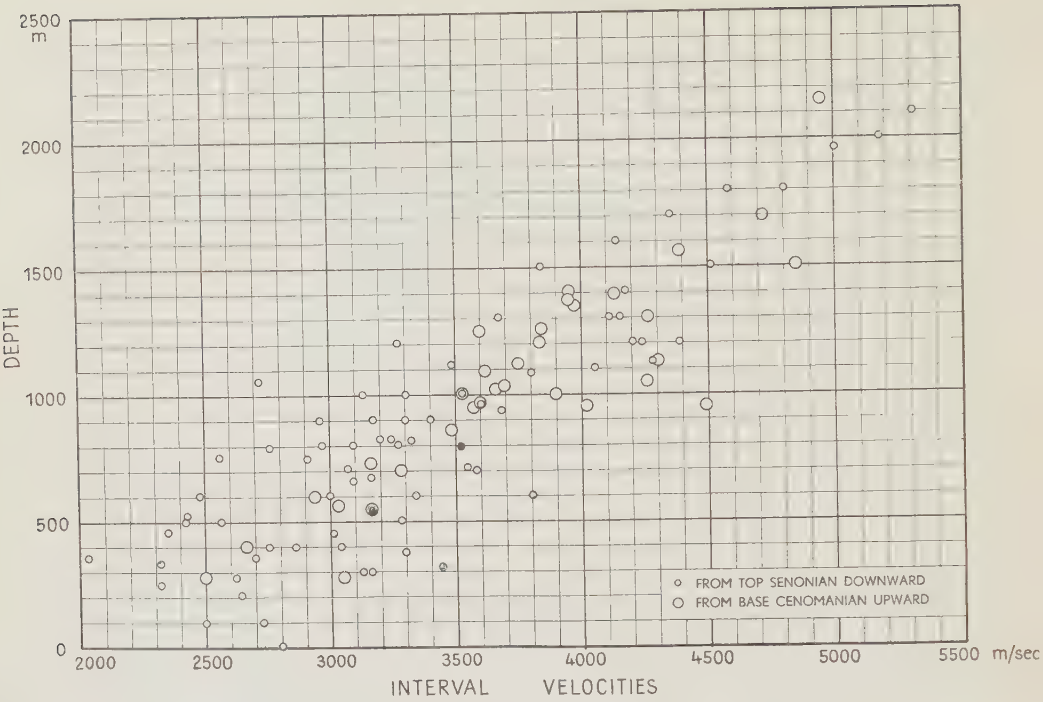

Fig. 4. Upper Cretaceous. Depth interval ca. 300 metres.

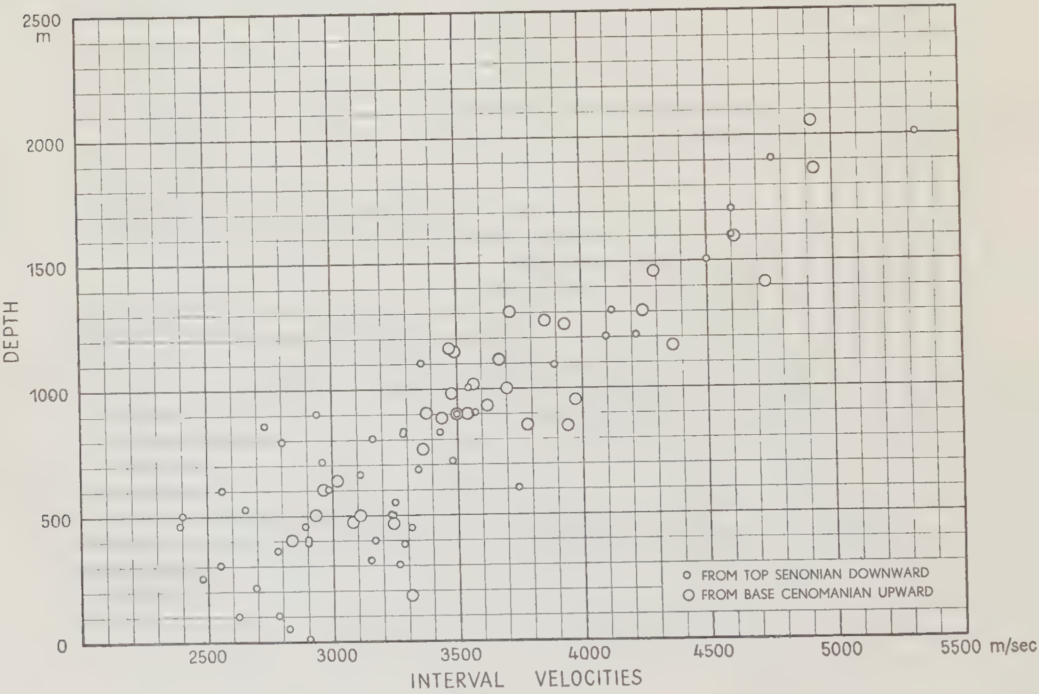

Fig. 5. Upper Cretaceous. Depth interval ca. 400 metres.

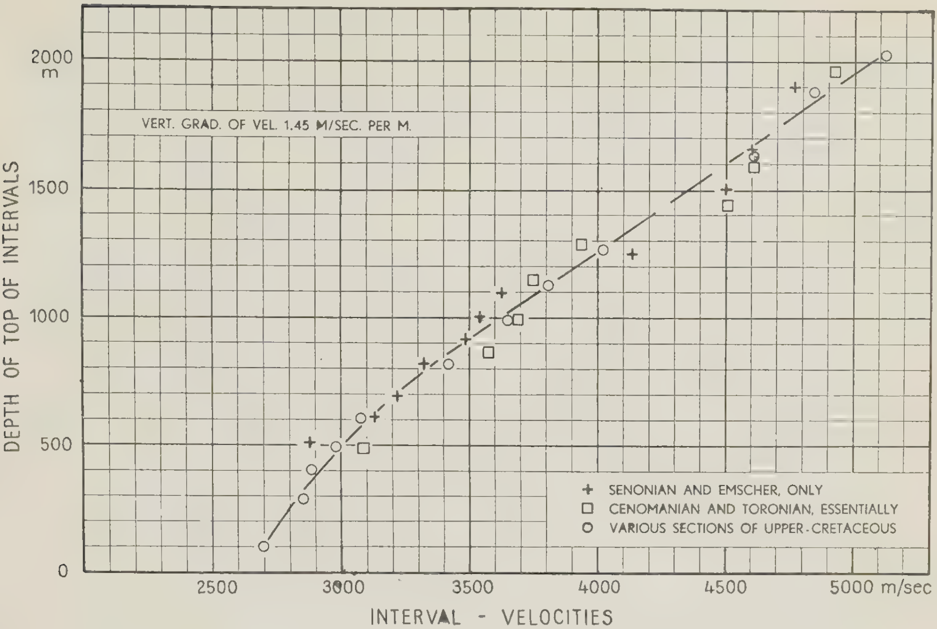

Fig. 6. Interval Velocities in different sections of Upper-Cretaceous (for Intervals of 400 metres) plotted against depth of Top of Intervals.

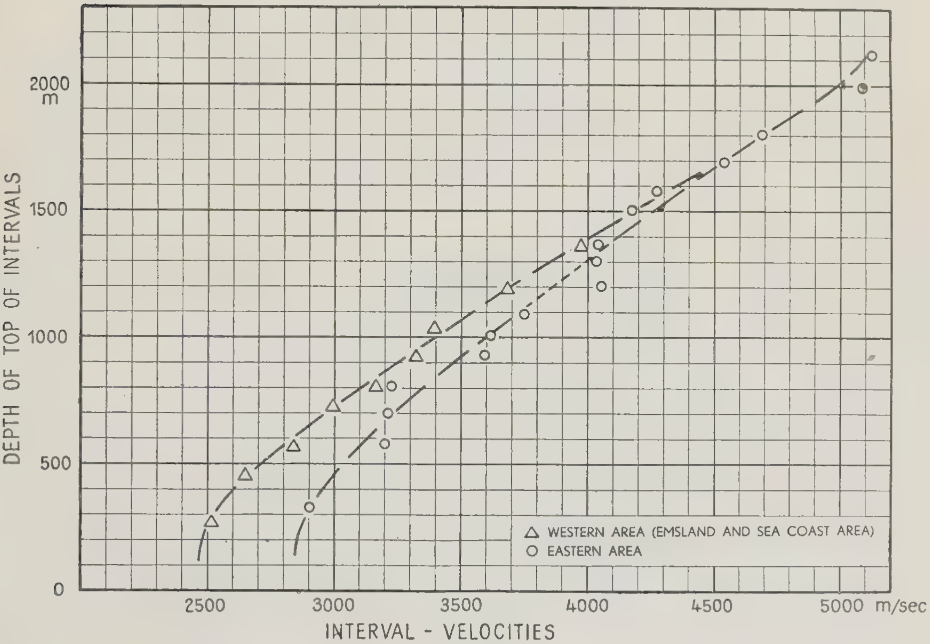

Fig. 7. Interval Velocities in different sections of Upper-Cretaceous (for Intervals of 300 metres) plotted against depth of Top of Intervals.

only 80 metres to as much as 280 metres. Although. the observational error increases for smaller intervals, only a slight scattering of the points is to be observed for the major part of the curve. Evidently, due to the uniform lithologic character of the section, the velocity chiefly depends on the thickness of overburden. The vertical gradient for this section (Albian) amounts to 1.0 metres/second per metre.

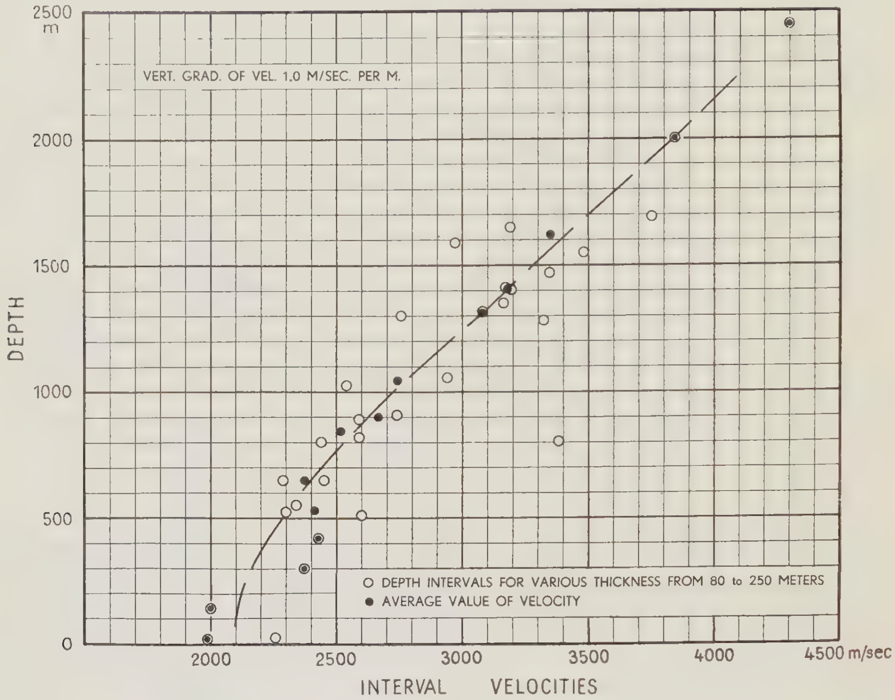

Fig. 8. Lower-Cretaceous (Albian).

The extreme value observed in Flachstöckheim has not been considered, as the data obtained from other sections in this well exhibit extraordinarily great deviations from the mean velocity curve. This may be due to intensive lithification caused by the adjacent salt structure.

In the preceeding figures examples were given, in which it was possible to draw some generalized curves representing approx. the rate of increase of velocity with depth or the dependence of velocity on thickness of overburden, respectively. The following figures 9, 10 and 11 are less encouraging.

Fig. 9 shows interval velocities obtained from different sections of the Wealden (Lower Cretaceous), consisting of a series of sandstones and shales.

Fig. 10 represents interval velocities vs. depth from Lower Jurassic (Lias), mainly built up by shales, A low rate of increase of velocity is to be noticed.

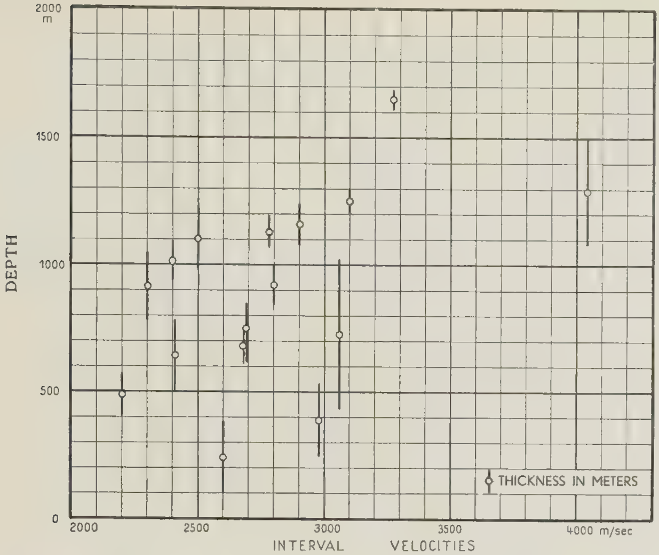

Fig. 9. Lower-Cretaceous (Valendis-Wealden).

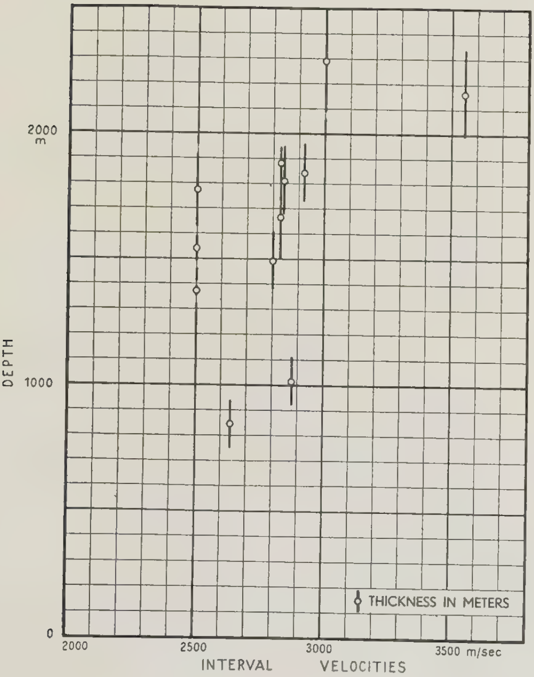

Fig. 10. Jurassic (Lias).

Fig. 11 shows interval velocities vs. depth from Upper Triassic (Keuper). This formation is known for its rapid lithologic variation and consists of sandstone, shales and more or less thick salinar beds.

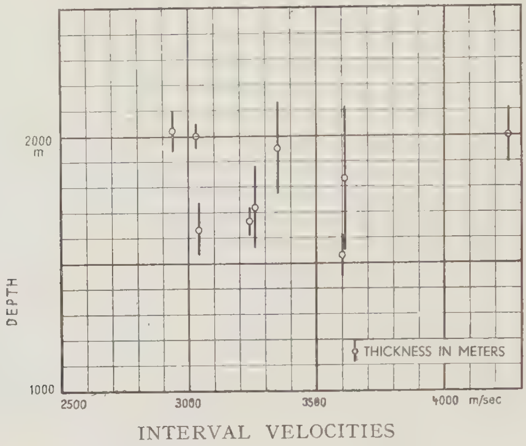

Fig. 11. Triassic (Keuper).

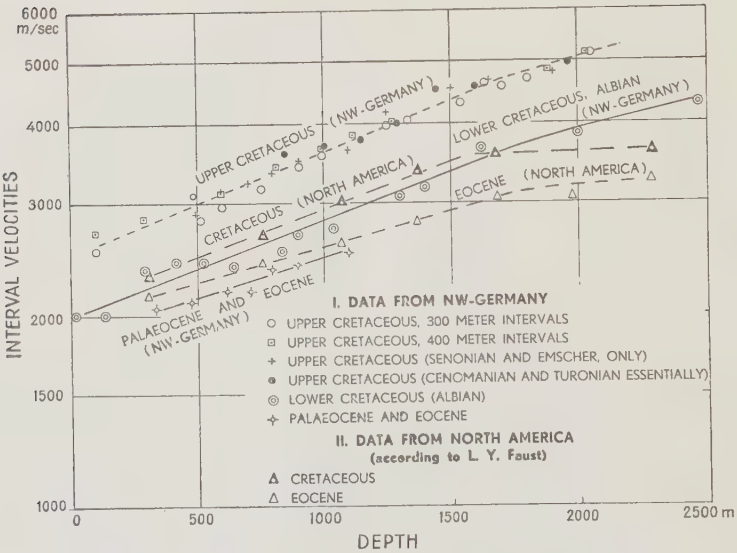

Fig. 12. Interval Velocities of different geologic sections plotted against depth.

Lithologic variation, internal structure of the sediments are considered as the main reasons for the rather irregular distribution of the velocity vs. depth points. But it has also to be borne in mind that only a few observations are available for an analysing study.

A composite graph of interval velocity against depth curves as described in Figs 2, 6, 7, and 8 are plotted on simple logarithmic paper in Fig. 12 together with corresponding curves determined in North America by L. Y. Faust [3]. The results obtained by Haskell [2] who found a much smaller gradient for Tertiary beds are not considered in this study.

It will be seen from the graph that the curves may be expressed by an exponential function. The trend of the curves reveals further the fact that they approach a maximum value with increasing depth. Comparing the velocity vs. depth curves from North West Germany with those from North America we find that, with regard to depth and rate of increase, the Eocene and Albian curves are quite similar to the curves determined for Eocene and Cretaceous in North America. The curve for Upper Cretaceous, on account of its high lime content, has no counterpart in the American literature. Furthermore, the American curves tend to attain their maximum values earlier than those from North West Germany. It is also noteworthy that in the normal geological section of North West Germany, rather thick beds of high velocities (Upper Cretaceous) are underlain by beds of relative low velocities (Lower Cretaceous) (Jurassic).

It is hoped that by this extract from the study of interval velocities in North West Germany not only the difficulties involved in this work but also some interesting features of the sedimentary sections have been shown and that future well surveying will extend our knowledge of the relations between velocities, lithologic structure and depth of formations.

LITERATURE

[1] WEATHERBY, B. B. and FAUST, L. Y., "Influence of geological Factors on Longitudinal Seismic Velocities, Bull. A. A. P. G. Vol. 19 (1935), 1-8.

[2] HASKELL, N. A., "The relation between depth, lithology and seismic wave velocity in Tertiary Sandstones and Shales", Geophysics Vol. VI (1941), 318-326.

[3] FAUST, L. Y., "Seismic Velocity as a Function of Depth and Geologic Time", Geophysics Vol. XVI (1951), 192-206.

DISCUSSION

Mr. v. HELMS: From velocity data obtained in refraction surveying, it is evident that such velocities increase with depth. This has been proved especially with regard to Upper Cretaceous. The velocity increases from about 3000 metres per second to about 5400 metres per second for depths from about 500 metres to about 2300 metres. I think that these values agree very well with the data presented by Mr. Tuchel with regard to Upper Cretaceous.

Mr. TUCHEL: The data given in this paper are not expected to be exactly the same as those obtained from refraction work; but the gradient of increase of velocity may help in judging the velocities at increasing depths.

Mr. KREY: With regard to older strata, as Wealden and Jurassic, higher velocities may be expected at shallower depths if such beds have been lifted upward from greater depths.

Mr. TUCHEL: Such effect will occur only if the lithological character of the sediment was strongly modified at greater depth (Foliation, schistosity etc.).

Mr. KUNZ: I am impressed on the fact of an increase of velocity with depth and I do not understand why so little use is made of this effect.

Mr. TUCHEL: Evidently certain strata of the geological section of North West Germany exhibit an increase but others do only slightly. The effect is well known and has been duly considered in computational work for a long time. It should not be forgotten that the high velocity layers of Upper Cretaceous age are underlain by strata of lower velocities.

Mr. RICHARD: Je voudrais savoir si les vitesses ont été mesurés dans des couches horizontales ou inclinées.

Mr. TUCHEL: The velocities were obtained from generally flat dipping beds. Some extraneous velocity data caused by steep dipping beds on the side of a salt dome were discarded.

CALCUL DU GRADIENT VERTICAL DU CHAMP DE GRAVITE ou DU CHAMP MAGNETIQUE MESURE A LA SURFACE DU SOL *

PAR

V. BARANOV *

Abstract

It is known that good use can be made of calculating the second vertical derivative of gravitational and magnetic fields. The first derivative, or Vertical Gradient, has the same properties, Like the second derivative, it does not depend on the locally linear regional anomaly. Moreover, the gradient is less affected by experimental errors.

The report gives a practical method of calculating the vertical gradient. Its application is identical to that in general use for calculating the second derivative, except that the numerical coefficients are different. The method also allows the establishment of formulae for downward extension of the field and its derivatives.

Il ne semble pas nécessaire d'insister sur l'utilité de calculer les dérivées verticales de la pesanteur. Le calcul de la seconde dérivée se fait maintenant couramment par la méthode de T. A. Elkins et L. J. Peters exposée sur les pages de „Geophysics". Les articles traitant ce sujet sont trop bien connus pour avoir besoin d'être rappelés. Il y a lieu de citer, pourtant, un article de H. A. Evjen [1] dans lequel l'auteur traite plusieurs exemples et insiste sur l'utilité de calculer le gradient en connaissant le champ g. Personne n'a jamais douté de cette utilité, mais, en fait, le calcul du gradient vertical s'est révélé difficile, et aucune méthode pratique n'a été élaborée. Par contre, il est apparu assez tôt que le calcul de la seconde dérivée peut se faire beaucoup plus aisément. C'est probablement pour cette raison qu'à l'heure actuelle on ne parle pas de gradient, mais que l'emploi de la seconde dérivée est si chaudement recommandé.

Pourtant, il est indéniable qu'à plusieurs points de vue le gradient vertical convient mieux à l'interprétation gravimétrique que la seconde dérivée. En effet, en dérivant deux fois par rapport à z on détruit deux constantes arbitraires et, par conséquent, on obtient un tableau plus éloigné de la réalité que la carte de gradient qui ne fait abstraction que d'une seule constante additive. Dernièrement Raoul Vajk [2] a insisté sur cet inconvénient.

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* Presented at the Hannover Meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

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Mais, il y a encore un second inconvénient qui est plus grave: la seconde dérivée est beaucoup plus sensible aux erreurs de mesure que le gradient. En effet, si l'on prend une courbe expérimentale quelconque défine par une suite de points affectés d'erreurs de mesure, il sera encore possible, sans trop d'erreurs, de déterminer une tangente à cette courbe, mais la détermination de son rayon de courbure est une entreprise beaucoup plus incertaine. Par conséquent, le gradient vertical bien calculé doit être, à priori, relativement plus précis que la seconde dérivée.

Peut-être les anomalies qui apparaissent sur la carte de gradient sont-elles un peu moins différenciées que celles de la seconde dérivée, mais nous verrons qu'il est possible d'accroître le pouvoir séparateur du gradient dans une très large mesure en prolongeant le champ vers le bas. On verra également que le gradient n'est pas affecté par une anomalie régionale localement linéaire. La carte gravimétrique de gradient possède donc les mêmes propriétés utiles que celle de seconde dérivée.

Commençons par rappeler les formules classiques qui donnent le champ g au-dessus du plan de mesures. En désignant par $\bar{g}\ (\rho)$ l'anomalie moyenne sur le cercle de rayon ρ, c'est-à-dire en posant

$$\bar{g}\,(\rho) = \frac{1}{2\,\pi}\int_0^{2\,\pi} g\,(\rho,\,\omega)\,d\,\omega$$

la valeur du champ en un point $+z$ de l'axe Oz sera donnée par l'expression suivante:

$$g\,(o,\,o,\,z) = \int_0^{\infty} \bar{g}\,(\rho)\,\frac{z\,\rho\,d\,\rho}{(\rho^2 + z^2)^{2/3}}.$$

C'est cette formule fondamentale que nous allons examiner en nous plaçant à un point de vue plus général et plus abstrait. Considérons une fonction quelconque $f(\rho)$ définie sur la demi-droite $o\rho$, donc pour tout ρ positif, et calculons une autre fonction que je désigne par $\hat{f}(z)$ en posant

$$\hat{f}\,(z) = \int_0^{\infty} f\,(\rho)\,\frac{z\,\rho\,d\,\rho}{(\rho^2 + z^2)^{2/3}} \quad . \; . \; . \; . \; . \; . \; . \; . \qquad (1)$$

Cette relation exprime ce qu'on appelle une transformation fonctionnelle. La fonction-argument $f(\rho)$ se trouve transformée en une autre fonction $\hat{f}(z)$ appelée „fonctionnelle de f". L'expression

$$\frac{z\,\rho}{r^3} = \frac{z\,\rho}{(\rho^2 + z^2)^{2/3}}$$

est le noyau de la transformation.

Dans le cas de la gravimétrie, la fonction donnée $f(\rho)$ est le champ gravimétrique moyen

$$f(\rho) = \overline{g}(\rho)$$

et la fonction transformée est $\hat{f}(z) = \overline{g}(z) = g(0,0,z)$.

D'une façon analogue dans le cas du magnétisme, $f(\rho)$ sera l'anomalie magnétique moyenne sur le cercle de rayon ρ et la fonction transformée $\hat{f}(z)$ représentera l'anomalie magnétique au point de cote $+z$ sur la verticale à l'origine des coordonnées.

Voici un troisième exemple. Considérons une distribution quelconque de masses sur le plan $z = 0$. Alors si f est la densité moyenne de ces masses sur le cercle de rayon ρ, la fonction $\hat{f}$ sera, à un facteur constant près, le champ de gravité provoqué par la distribution. On a, en effet,

$$g(0, 0, z) = 2\pi k \, . \, \hat{f}(z)$$

où k est la constante de gravitation $k = 66{,}7.10^{-9}$.

Ce dernier exemple est particulièrement instructif. Les masses peuvent être distribuées d'une façon absolument quelconque. Par conséquent, la fonction f dans le cas général n'est certainement par analytique. Il est donc vain de chercher à la représenter à l'aide d'une série de Taylor. Mais, dans ce cas, nous n'avons plus aucune raison d'employer ce procédé pour exprimer la fonction transformée $\hat{f}$.

Signalons encore une seconde difficulté. Il est bien connu que l'intégrale (1) ne représente la fonction $\hat{f}(z)$ que pour des valeurs positives de z. En posant, sans précaution, $z = 0$, on trouve $\hat{f}(0) = 0$. Or, la vraie valeur est

$$\hat{f}(0) = f(0)$$

Le résultat erroné s'explique par le fait que la fonction sous le signe somme admet pour $z = 0$ un élément singulier à l'origine : si ρ est nul en même temps que z, la fonction à intégrer a une valeur infinie. Cette difficulté peut être évitée par un procédé classique et nous n'insistons pas ici sur ces calculs élémentaires. Dans l'Annexe on trouvera une démonstration du théorème suivant :

> Si la fonction $f(\rho)$ est continue à l'origine et bornée pour toute valeur de ρ, la fonction transformée $\hat{f}(z)$ est continue pour $z = 0$ et sa valeur en ce point est $f(0)$.

Il faut noter spécialement le fait que la fonction donnée $f(\rho)$ peut présenter des discontinuités en nombre quelconque ; elle doit être continue seulement à l'origine. Pour s'exprimer brièvement, on peut dire que c'est l'intégrale (1), simplement, qui est discontinue ; quant à la fonction transformée $f(z)$, elle est continue même pour $z = 0$.

La principale conclusion à en tirer est que nous n'avons aucun droit de dériver sous le signe somme, pour calculer la dérivée $f'(0)$. Il faut donc intégrer d'abord et dériver ensuite. Mais cette dérivée existe-t-elle ? On ne peut pas évidemment aborder le calcul avant d'avoir déterminé les conditions d'existence.

On trouvera dans l'Annexe la démonstration du théorème suivant:

> Si la fonction intégrable $f(\rho)$ admet à l'origine une dérivée (d'ailleurs nulle) remplissant une condition de Lipschitz, c'est-à-dire s'il existe un nombre positif η tel que l'inégalité
>
> $$\rho < \eta$$
>
> entraîne la condition
>
> $$| f(\rho) - f(0) | < A . \rho^2$$
>
> A étant un nombre fixe quelconque, et si, en outre, la fonction $f(\rho)$ est bornée pour tout ρ, la fonction transformée $\hat{f}(z)$ admet une dérivée pour $z = 0$.

Cette condition suffisante est, en réalité, un peu forte: on peut montrer, par exemple, que la borne A peut croître comme le logarithme de $(1/\rho)$. Mais nous n'insisterons pas ici sur cet aspect mathématique du problème.

La fonction $f(\rho)$ est toujours paire, et sa dérivée est impaire. On ne peut pourtant pas en conclure que cette dérivée est nulle pour $\rho = 0$. Il faut d'abord qu'elle y soit continue. Pratiquement, pour que $f(\rho)$ admette une dérivée qui s'annule comme ρ, il suffit que la surface $f(\rho, \omega)$ soit pourvue d'un plan tangent unique à l'origine (voir l'Annexe).

Ces principes étant posés, nous pouvons nous attaquer au calcul de la dérivée $\hat{f}'(0)$.

Nous ne dirons que quelques mots sur le calcul de la fonction moyenne $f(\rho)$. Posons avec Elkins

$$f(\rho) = \frac{1}{2\pi}\int_0^{2\pi} f(\rho, \omega) = \frac{1}{n}\sum_{\nu=1}^{n} f(\rho, \omega_\nu)$$

En ce qui concerne les rayons successifs ρ, voici les valeurs canoniques que nous avons adoptées:

$$0 - 1 - \sqrt{2} - \sqrt{5} - \sqrt{10} - \sqrt{17} - \sqrt{25} - \sqrt{40} - \sqrt{68} - \sqrt{100}$$

Le nombre des points sur ces cercles est de:

$$1 - 4 - 4 - 8 - 8 - 12 - 12 - \dots$$

Le cercle de rayon $\sqrt{17}$ passe par les points $(\pm 4, \pm 1)$ et $(\pm 1, \pm 4)$ et très près des 4 points $(\pm 3, \pm 3)$. Remarque analogue au sujet du cercle $\sqrt{68}$.

Ainsi donc, la fonction $f(\rho)$ est connue en une dizaine de points isolés. Elle peut être qualifiée comme une courbe expérimentale, malgré le calcul préliminaire des moyennes. Nous avons vu que la première opération à faire est l'intégration exprimée par la formule (1). C'est seulement après avoir effectué cette intégration que nous avons le droit de dériver par rapport à z.

Il existe plusieurs procédés connus pour obtenir la valeur approchée d'une intégrale. Tous sont basés sur une représentation de la fonction à intégrer à l'aide d'une formule mathématique simple, généralement un polynôme. Il est d'ailleurs impossible de trouver une formule unique, pour représenter toutes les courbes de $\rho = 0$ à $\rho = \infty$. On est obligé de partager l'intervalle $(0, \infty)$ en des intervalles partiels et de chercher une représentation de la courbe expérimentale séparément dans chacun de ces intervalles à l'aide des formules appropriées.

Pour ces intervalles, nous prenons ceux qui sont naturellement définis par les abscisses canoniques, et, dans chacun des intervalles, nous assimilons la courbe expérimentale à une parabole biquadratique

$$f_k(\rho) = a_k + b_k \rho^2 + c_k \rho^4$$

Une remarque spéciale doit être faite au sujet du dernier intervalle $(k = 10)$ qui va de $\rho = 10$ à l'infini. Comme la fonction f est bornée à l'infini, on peut poser simplement

$$f_{10}(\rho) = a_{10} + \frac{b_{10}}{\rho}$$

Pour le premier intervalle partiel $(0,1)$ il est essentiel de ne considérer que les puissances paires de ρ, car la dérivée à l'origine est nulle et la fonction f est paire. Pour les autres segments, la parabole biquadratique est choisie uniquement pour des raisons d'uniformité et de commodité.

Nous avons posé comme principe que la courbe f définie mathématiquement doit, obligatoirement, passer par tous les points canoniques expérimentaux. En effet, ce sont les seuls points dont nous sommes sûrs, et ils ne sont pas déjà suffisamment nombreux pour qu'on soit autorisé à faire passer la courbe théorique à côté. C'est pour cette raison que nous n'avons pas voulu avoir recours à la méthode des moindres carrés.

Considérons d'abord le premier intervalle $(0,1)$. La représentation de la fonction f au voisinage de l'origine doit être particulièrement précise car les propriétés de la fonction transformée $\hat{f}(z)$ dépendent surtout du début de la courbe $f(\rho)$. Or, pour définir les trois coefficients de l'équation

$$f_1(\rho) = a_1 + b_1 \rho^2 + c_1 \rho^2$$

nous n'avons que deux conditions

$$f(0) = f_0 \qquad \text{et} \qquad f(1) = f_1$$

On en tire

$$\begin{aligned} a_1 &= \quad f_0 \\ b_1 &= -f_0 + f_1 - c_1 \end{aligned}$$

L'expérience nous a montré qu'il est difficilement acceptable de poser $c_1 = 0$ en se limitant à deux termes: il faut tenir compte du point suivant d'abscisse $\sqrt{2}$ et d'ordonnée f_2. Même le point $(\sqrt{5}, f_3)$ influe légèrement sur l'allure de la courbe dans l'intervalle (0,1). Voici, finalement, la méthode qui s'est révélée satisfaisante.

En laissant c_1 indéterminé, nous obtenons l'équation

$$f_1 (\rho) = f_0 + (f_1 - f_0 - c_1)\,\rho^2 + c_1\,\rho^4$$

d'où

$$c_1 = \frac{f(\rho) - f_0 + (f_0 - f_1)\,\rho^2}{\rho^2\,(\rho^2 - 1)}$$

Essayons d'abord de faire passer la courbe par le point $\rho = \sqrt{2}$, $f(\sqrt{2}) = f_2$. La valeur de c_1 sera

$$c'_1 = \frac{1}{2} f_0 - f_1 + \frac{1}{2} f_2$$

En faisant, ensuite, $\rho = \sqrt{5}$ et $f(\rho) = f(\sqrt{5}) = f_3$ on obtient une autre valeur de c_1

$$c''_1 = \frac{1}{5} f_0 - \frac{1}{4} f_1 + \frac{1}{20} f_3$$

et la courbe théorique passera maintenant par le point $(\sqrt{5}, f_3)$.

La vraie valeur de c_1 doit être comprise entre ces deux limites, et se trouver d'ailleurs plus près de c'_1. On peut donc poser

$$c_1 = (1 - \lambda)\, c'_1 + \lambda\, c''_1$$

Le paramètre λ a été déterminé expérimentalement en examinant un grand nombre de courbes typiques. Nous avons ainsi trouvé que la valeur $\lambda = 1/5$ convient bien. Alors

$$c_1 = \frac{4}{5} c'_1 + \frac{1}{5} c''_1$$

L'influence du point $(\sqrt{2}, f_2)$ sur l'allure de la courbe dans l'intervalle (0,1) est quatre fois plus forte que celle du point $(\sqrt{5}, f_3)$. La formule définitive est

$$\begin{aligned} f(\rho) = f_0 &+ \left(-\frac{36}{25} f_0 + \frac{37}{20} f_1 - \frac{2}{5} f_2 - \frac{1}{100} f_3\right) \rho^2 \\ &+ \left(\frac{11}{25} f_0 - \frac{17}{20} f_1 + \frac{2}{5} f_2 + \frac{1}{100} f_3\right) \rho^4 = \\ &= \left(1 - \frac{36}{25} \rho^2 + \frac{11}{25} \rho^4\right) f_0 + \left(\frac{37}{20} \rho^2 - \frac{17}{20} \rho^4\right) f_1 + \\ &+ \left(-\frac{2}{5} \rho^2 + \frac{2}{5} \rho^4\right) f_2 + \left(-\frac{1}{100} \rho^2 + \frac{1}{100} \rho^4\right) f_3 \end{aligned}$$

En passant, notons que la seconde dérivée est, comme on le sait, le coefficient de ρ^2 multiplié par -4; donc

$$\hat{f}''(0) = \frac{144}{25} \cdot f_0 - \frac{37}{5} f_1 + \frac{8}{5} f_2 + \frac{1}{25} f_3$$

Cette formule donne une valeur très exacte de la seconde dérivée. Nous reviendrons encore à son examen.

Considérons maintenant les intervalles suivants. La courbe théorique doit passer par deux points canoniques, — les extrémités de l'intervalle. Nous avons donc deux conditions

$$a_k + b_k \cdot \rho^2_{k-1} + c_k \cdot \rho^4_{k-1} = f_{k-1}$$
$$a_k + b_k \rho^2_k + c_k \rho^4_k = f_k$$

Pour trouver la meilleure valeur du coefficient c_k, nous essayerons d'abord de faire passer la courbe par le point canonique voisin à gauche de l'intervalle k, ce qui nous fournit la troisième condition

$$a_k + b_k \cdot \rho^2_{k-2} + c_k \cdot \rho^4_{k-2} = f_{k-2}$$

En second lieu nous admettrons que la courbe passe par le point canonique voisin situé à droite de ρ_k. Dans ce cas la troisième condition sera

$$a_k + b_k \cdot \rho^2_{k+1} + c_k \cdot \rho^4_{k+1} = f_{k+1}$$

Nous pouvons donc calculer deux courbes différentes, mais très voisines en utilisant l'une ou l'autre de ces conditions. La courbe expérimentale sera très voisine de la moyenne de deux courbes théoriques.

Il est inutile d'écrire l'expression de $f_k(\rho)$ sous sa forme générale algébrique. Nous allons tout-à-l'heure donner les valeurs numériques calculées par cette méthode sous forme d'un tableau.

En ce qui concerne le dernier intervalle partiel $(10, \infty)$ nous avons défini les coefficients a_{10} et b_{10} de façon à ce que la courbe théorique passe par deux derniers points canoniques.

Ainsi, toute la courbe f est bien définie à l'aide des coefficients a_k, b_k, c_k qui s'expriment linéairement en fonction des valeurs canoniques f_ν $(\nu = 0, 1, 2, \dots 9)$. On peut poser, en général,

$$\begin{aligned} a_k &= \sum_{(\nu)} \alpha_{k\,\nu} f_\nu \\ b_k &= \sum_{(\nu)} \beta_{k\,\nu} f_\nu \qquad \dots\dots\dots\dots (2) \\ c_k &= \sum_{(\nu)} \gamma_{k\,\nu} f_\nu \end{aligned}$$

où α, β, γ sont des constantes numériques calculées une fois pour toutes et qui figurent dans le tableau I.

C'est cette représentation qui est à la base de notre méthode. Elle s'avère très bonne, mais les essais ne sont pas encore tout à fait terminés, et, si nous

α	
	β
	γ

ρ	0	1	$\sqrt{2}$	$\sqrt{5}$	$\sqrt{10}$	$\sqrt{17}$	$\sqrt{25}$	$\sqrt{40}$	$\sqrt{68}$	$\sqrt{100}$
k \ ν	0	1	2	3	4	5	6	7	8	9
1 0 − 1	1,00000 -1,44000 0,44000	0 1,85000 -0,85000	0 -0,40000 0,40000	0 -0,01000 0,01000						
2 $1-\sqrt{2}$	0,50000 -0,75000 0,25000	1,25000 0,12500 -0,37500	-0,83333 0,75000 0,08333	0,08333 -0,12500 0,04167						
3 $\sqrt{2}-\sqrt{5}$		1,25000 -0,87500 0,12500	0,20833 0,68750 -0,14583	-0,58333 0,27500 0,00833	0,12500 -0,08750 0,01250					
4 $\sqrt{5}-\sqrt{10}$			1,04167 -0,31250 0,02083	0,75000 0,17500 -0,02500	-1,08929 0,22679 -0,00178	0,29762 -0,08929 0,00595				
5 $\sqrt{10}-\sqrt{17}$				1,41667 -0,22500 0,00833	0,80952 0,11429 -0,00952	-1,93452 0,22321 -0,00298	0,70833 -0,11250 0,00417			
6 $\sqrt{17}-5$					2,02381 -0,20000 0,00476	0,48525 0,13587 -0,00621	-2,12500 0,12500 0	0,61594 -0,06087 0,00145		
7 $5-\sqrt{40}$						2,71739 -0,17663 0,00272	-0,72480 0,15378 -0,00339	-1,40787 0,04984 0,00026	0,41528 -0,02699 0,00041	
8 $\sqrt{40}-\sqrt{68}$							2,10853 -0,08372 0,00077	0 0,06071 -0,00089	-1,81686 0,05113 -0,00014	0,70833 -0,02812 0,00026
9 $\sqrt{68}-10$								4,04762 -0,10000 0,00060	-4,46429 0,15625 -0,00112	-1,41667 -0,05625 0,00052
10 $10-\infty$									-4,70194 47,01941 0	5,70194 -47,01941 0

Tableau I. Coefficients de représentation de la courbe $f(\rho)$ — Coefficients of curve $f(\rho)$.

réussissons à réaliser une meilleure représentation de la courbe expérimentale, un prochain article exposera les résultats obtenus.

Nous sommes en mesure, maintenant, de calculer l'intégrale (1) en la traitant comme une somme

$$\hat{f}(z) = \sum_{(k)} \int (a_k + b_k \rho^2 + c_k \rho^4) \frac{z \rho \, d\rho}{r^3} \quad . \; . \; . \; . \; . \quad (3)$$

avec

$$r^2 = z^2 + \rho^2$$

dont chaque terme correspond à un intervalle partiel. En portant (2) dans (3) on obtient

$$\hat{f}(z) = \sum_{(\nu)} f_\nu \sum_{(k)} \int (\alpha_{k\,\nu} + \beta_{k\,\nu} \rho^2 + \gamma_{k\,\nu} \rho^4) \frac{z \rho \, d\rho}{r^3}$$

Ainsi, donc, nous avons fait apparaître les coefficients $F_\nu(z)$ par lesquels il faut multiplier les valeurs canoniques pour obtenir la fonction transformée. Ces coefficients sont les fonctions de z

$$F_\nu(z) = \sum_{(k)} \int (\alpha_{k\,\nu} + \beta_{k\,\nu} \rho^2 + \gamma_{k\,\nu} \rho^4) \frac{z \rho \, d\rho}{r^3} \quad . \; . \; . \; . \; . \quad (4)$$

calculées une fois pour toutes. L'expression définitive de la fonction transformée est

$$f(z) = \sum_{(\nu)} f_\nu F_\nu(z) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

L'intégration (4) est élémentaire. Notons, pour mémoire, la valeur de l'intégrale indéfinie

$$\int (\alpha_{k\,\nu} + \beta_{k\,\nu} \rho^2 + \gamma_{k\,\nu} \rho^4) \frac{z \rho \, d\rho}{r^3} = z\, r \left((\beta_{k\,\nu} - 2\, \gamma_{k\,\nu} z^2 + \frac{1}{3} \gamma_{k\,\nu} r^2 \right) -$$

$$- \frac{z}{r} \left(\alpha_{k\,\nu} - \beta_{k\,\nu} z^2 + \gamma_{k\,\nu} z^4 \right)$$

où il suffit de substituer les abscisses des extrémités de l'intervalle k.

Pour le dernier intervalle (le dixième) nous avons, par exception

$$\int \left(a_{10} + \frac{b_{10}}{\rho} \right) \frac{z \rho \, d\rho}{r^3} = \frac{b_{10} \rho - a_{10} z^2}{z\, r}$$

On obtient l'expression générale suivante

$$I_{k\,\nu} = \int_{\rho_{k\quad 1}}^{\rho_k} \left(\alpha_{k\,\nu} + \beta_{k\,\nu}\,\rho^2 + \gamma_{k\,\nu}\,\rho^4\right) \frac{z\,\rho\,d\,\rho}{r^3} =$$

$$= z\left(\frac{1}{R_{k-1}} - \frac{1}{R_k}\right)\left(\alpha_{k\,\nu} - \beta_{k\,\nu}\,z^2 + \gamma_{k\,\nu}\,z^4\right) +$$

$$+ z\,(R_k - R_{k-1})\,(\beta_{k\,\nu} - 2\,\gamma_{k\,\nu}\,z^2) +$$

$$+ \frac{1}{3}\,\gamma_{k\,\nu}\,z\left(R^3_k - R^3_{k-1}\right)$$

avec l'abréviation

$$R^2_k = \rho^2_k + z^2$$

Pour le premier intervalle, étant donné que $R_0 = z$ cette expression s'écrit

$$I_{1\,\nu} = \left(1 - \frac{z}{R_1}\right)\left(\alpha_{1\,\nu} - \beta_{1\,\nu}\,z^2 + \gamma_{1\,\nu}\,z^4\right) +$$

$$+ z\left(R_1 - z\right)\left(\beta_{1\,\nu} - 2\,\gamma_{1\,\nu}\,z^2\right) + \frac{1}{3}\gamma_{1\,\nu}\,z\left(R_1{}^3 - z^3\right)$$

Enfin, l'intégrale correspondant au dernier intervalle est

$$I_{10\,,\,\nu} = \frac{\alpha_{10\,,\,\nu}\,z}{R_9} + \frac{\beta_{10\,,\,\nu}}{z}\left(1 - \frac{\rho_9}{R_9}\right) =$$

$$= \alpha_{10\,,\,\nu}\,\frac{z}{\sqrt{z^2 + 100}} + \frac{\beta_{10\,,\,\nu}}{z}\left(1 - \frac{10}{\sqrt{z^2 + 100}}\right)$$

Le fait important que nous devons noter ici est la continuité et la dérivabilité des fonctions $F_\nu(z)$. Nous l'avions déjà prévu et démontré (Annexe). Contrairement à l'intégrale (1) qui est discontinue, les fonctions $F_\nu(z)$ ne subissent aucune discontinuité pour $z = 0$. Par conséquent, nous avons le droit de prolonger ces fonctions pour des valeurs négatives de z simplement en changeant le signe de z. Nous avons le droit également de dériver par rapport à z autant de fois que nous désirons et de faire, ensuite, $z = 0$. Ainsi donc, les formules que nous avons établies résolvent en même temps le problème du prolongement du champ au-dessous du plan de mesures et le problème du gradient vertical pour une cote z quelconque positive ou négative.

Par exemple, en dérivant deux fois par rapport à z et en posant, ensuite, $z = 0$ nous pouvons obtenir l'expression de la seconde dérivée $\hat{f}''(0)$ à la surface $z = 0$. Nous ne répèterons pas ici ce calcul, car nous avons déjà trouvé la seconde dérivée par une méthode plus rapide.

Une telle méthode ne réussit pas pour le gradient, car le développement de la fonction $f(\rho)$ en série ne dépend pas de la première dérivée. Nous allons donc, pour calculer le gradient, dériver une fois par rapport à z les fonctions $F_\nu(z)$ et poser, ensuite, $z = 0$. Bien entendu, on peut procéder plus simplement en cherchant les deux premiers termes du développement

$$F_\nu\,(z) = (1 \text{ ou } 0) + A_\nu\,.\,z + O\,(z^2)$$

Il nous faut seulement connaître le coefficient de z que nous avons désigné par A_ν. Le gradient est alors

$$\hat{f}\,'(0) = \sum_{(\nu)} A_\nu\, f_\nu$$

Les calculs exigés par cette méthode sont tout à fait élémentaires, et nous les omettons, pour ne pas surcharger cet exposé.

Voici la formule définitive:

$$\begin{aligned} -\hat{f}'(0) = &+ 2{,}30518.f(0) \\ &- 1{,}70975.f(1) \\ &- 0{,}05284.f(\sqrt{2}) \\ &- 0{,}17401.f(\sqrt{5}) \\ &- 0{,}09577.f(\sqrt{10}) \\ &- 0{,}05249.f(\sqrt{17}) \\ &- 0{,}04174.f(5) \\ &- 0{,}04038.f(\sqrt{40}) \\ &+ 0{,}20340.f(\sqrt{68}) \\ &- 0{,}34160.f(10) \end{aligned}$$

En particulier, s'il s'agit d'un champ de gravité, donc si $f = \overline{g}$, et si l'anomalie moyenne est exprimée en milligals, pour obtenir le gradient en eötvös, il faut multiplier la valeur calculée à l'aide de cette formule par le facteur $\frac{10.000}{a}$ où a est la longueur du coté de la grille en mètres.

En plus de cette formule, nous en avons établi plusieurs autres dont voici quelques-unes. La première donne la valeur de la fonction transformée f(z) au-dessous du plan de mesures pour $z = -1$; c'est le prolongement vers le bas:

$$\begin{aligned} \hat{f}(-1) = &+ 9{,}96129.f(0) \\ &- 12{,}14361.f(1) \\ &+ 3{,}56984.f(\sqrt{2}) \\ &- 0{,}04114.f(\sqrt{5}) \\ &- 0{,}08302.f(\sqrt{10}) \\ &- 0{,}04805.f(\sqrt{17}) \\ &- 0{,}03946.f(5) \\ &- 0{,}03894.f(\sqrt{40}) \\ &+ 0{,}20352.f(\sqrt{68}) \\ &- 0{,}34043.f(10) \end{aligned}$$

La seconde et la troisième formule donnent le prolongement du gradient vertical vers le bas à une distance égale respectivement à $z = -1/2$ et à $z = -1$ toujours en prenant pour l'unité le coté de la maille fondamentale de la grille.

Voici ces deux formules:

$$\begin{aligned} -\hat{f}'(-1/2) = &+ 7{,}59809 . f(0) \\ &- 9{,}62962 . f(1) \\ &+ 2{,}45772 . f(\sqrt{2}) \\ &- 0{,}07508 . f(\sqrt{5}) \\ &- 0{,}08560 . f(\sqrt{10}) \\ &- 0{,}04903 . f(\sqrt{17}) \\ &- 0{,}03998 . f(5) \\ &- 0{,}03927 . f(\sqrt{40}) \\ &+ 0{,}20349 . f(\sqrt{68}) \\ &- 0{,}34072 . f(10) \end{aligned}$$

$$\begin{aligned} -\hat{f}'(-1) = &+ 21{,}12473 . f(0) \\ &- 32{,}74384 . f(1) \\ &+ 11{,}69627 . f(\sqrt{2}) \\ &+ 0{,}22842 . f(\sqrt{5}) \\ &- 0{,}06022 . f(\sqrt{10}) \\ &- 0{,}03977 . f(\sqrt{17}) \\ &- 0{,}03510 . f(5) \\ &- 0{,}03612 . f(\sqrt{40}) \\ &+ 0{,}20373 . f(\sqrt{68}) \\ &- 0{,}33809 . f(10) \end{aligned}$$

L'influence gravimétrique croît rapidement avec la profondeur. Il est donc naturel que les coefficients de ces formules croissent également avec $-z$. Ceci est vrai surtout pour les trois premiers coefficients; les derniers coefficients varient peu et leur contribution est faible.

Nous avons vérifié ces formules en examinant un grand nombre d'exemples théoriques. Parmi les exemples traités nous avons choisi une douzaine de fonctions $f(\rho)$ d'allure caractéristique et facilement intégrables. Les formules et les courbes sont consignées dans le tableau II. Le paramètre h, variable d'une courbe à l'autre, caractérise l'acuité de l'anomalie. Les courbes deviennent moins pointues, lorsque h croît.

Dans la colonne suivante (2) figure la valeur théorique de la première dérivée et, dans la troisième colonne, la valeur de cette même dérivée calculée à l'aide de notre formule approchée. On constate que la coïncidence est extrêmement bonne, même pour les courbes f très pointues. Pour faciliter la comparaison des courbes, nous avons choisi les constantes de façon à ce que l'anomalie maximum soit la même pour chaque courbe. Cette valeur est égale à 100. L'unité de grille est la même pour chaque courbe: $a = 1$. Sans cette dernière restriction, la coïncidence serait encore meilleure, car il est naturel de choisir le „pas" a d'autant plus petit que la courbe est plus aigüe, c'est-à-dire l'anomalie plus localisée. Il faut d'ailleurs observer que les courbes du tableau qui correspondent aux petites valeurs de h sont beaucoup plus aigües que toute anomalie pouvant être rencontrée réellement dans des conditions normales.

Nous avons, ensuite, vérifié la formule pour la seconde dérivée. Les valeurs théoriques exactes de cette dérivée se trouvent dans la colonne 4, et les valeurs calculées à l'aide de notre formule approchée dans la colonne 5. Pour des courbes très pointues la coïncidence n'est pas aussi bonne, mais, comme nous l'avons dit tout-à-l'heure, de telles courbes sont exceptionnelles. Lorsque l'anomalie a une allure normale, la précision est plus que suffisante.

Dans la colonne 6 figure la valeur de la dérivée calculée à l'aide de l'excellente formule de M. Rosenbach.

Les deux colonnes suivantes du tableau donnent les résultats du prolongement du champ vers le bas à une distance égale au pas de la grille. La valeur théorique du champ se trouve dans la colonne 7, la valeur calculée à l'aide de la formule approchée dans la colonne 8. La conclusion est la même que tout-à-l'heure.

Enfin, les deux dernières colonnes du tableau sont relatives au prolongement du gradient vers le bas à une distance $z = 1/2$ du plan de mesures. Seules les courbes très aigües conduisent à des écarts appréciables. Comme toujours, la formule approchée tend à adoucir les anomalies locales très pointues et superficielles, mais c'est probablement un résultat souvent souhaitable. D'ailleurs, même dans ces cas extrêmes, il est possible de calculer le gradient avec une précision beaucoup plus grande, en choisissant une unité de longueur a plus petite pour mieux caractériser la courbe $f(\rho)$ expérimentale.

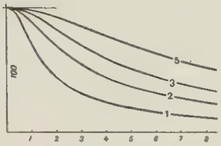
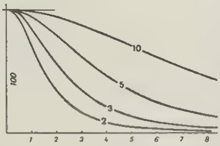
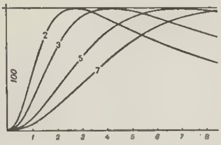
		1	2	3	4	5	6	7	8	9	10
		h	$-\hat{f}'(0)$		$\hat{f}''(0)$			$\hat{f}(-1)$		$-\hat{f}'(-\frac{1}{2})$	
			th	c	th	c	R	th	c	th	c
$f(\rho) = \frac{100h}{\sqrt{\rho^2+h^2}}$ $\hat{f}(z) = \frac{100h}{z+h}$		1	100	93.0	200	146.8	124.6	∞	336	400	212
		2	50	49,6	50	47,8	45,1	200	188	89	78
		3	33,3	33,2	22,2	21,9	21,6	150	149	48,0	47,2
		5	20	19,6	8,0	8,0	8 0	125	125	24,7	24,2
$f(\rho) = \frac{100h^3}{(\rho^2+h^2)^{3/2}}$ $\hat{f}(z) = \frac{100h^2}{(z+h)^2}$		2	100	97,9	150	134,8	122,7	400	319	237	200
		3	66,7	66,6	66,7	65,7	62,4	225	217	115	111
		5	40	40,5	24	23,9	23,7	156	156	54,9	55,1
		10	20	20,2	6	6,0	6,0	123	123	23,3	23,4
$f(\rho) = \frac{150\sqrt{3}\,h\rho^2}{(\rho^2+h^2)^{3/2}}$ $\hat{f}(z) = \frac{150\sqrt{3}\,hz}{(z+h)^2}$		2	-129.9	-125.6	-260	-227	-202	-520	-340	-385	-305
		3	-86.6	-86.8	-115.5	-111.1	-106.2	-195	-177	-174.6	-165.8
		5	-52.0	-54.4	-41.6	-41.3	-41.0	-81.2	-82.6	-78.4	-80.4
		7	-37.1	-40.9	-21.2	-21.2	-21.1	-50.5	-54.2	-49.7	-53.4
$f = 100e^{-\frac{\rho^2}{h}}$	$\hat{f} = 100 - 100z\sqrt{\frac{\pi}{h}}e^{\frac{z^2}{h}}\operatorname{erfc}\left(\frac{z}{\sqrt{h}}\right)$	10	56.05	56.0	40	39.9	39.6	183.3	182.8	81.0	80.7

Tableau II. Vérifications théoriques — Theoretical Proofs.

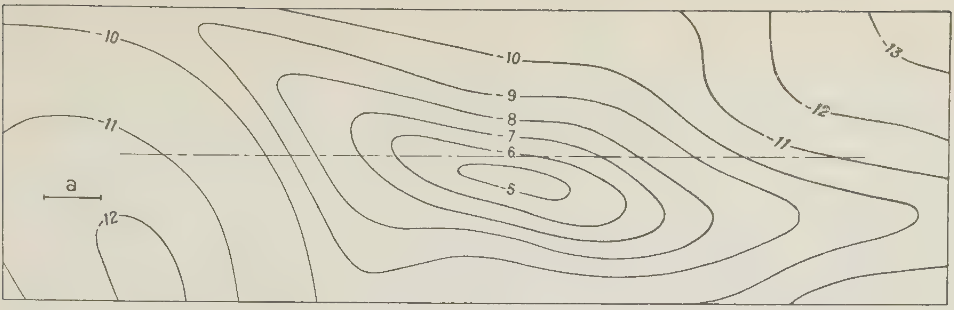
On constate que parmi toutes les formules étudiées, la plus précise est celle qui donne le gradient à la surface. C'est encore la formule qui est la moins influencée par les erreurs expérimentales, car les coefficients qui interviennent dans cette formule sont les plus petits.

Il y a peut-être une chose qu'on peut reprocher au gradient. Son calcul exige neuf cercles et neuf valeurs canoniques, tandis que pour le calcul de la seconde dérivée quatre points de la courbe expérimentale suffisent. Mais il faut remarquer, qu'en pratique, on n'a pas besoin d'aller si loin, car les coefficients diminuent rapidement. Six cercles sont bien suffisants dans tous les cas. On s'en rend compte en examinant la figure 1. Dans la partie supérieure de cette planche est représenté un extrait d'une carte de l'anomalie de Bouguer, tiré de l'une de nos études. Au milieu est tracé le profil gravimétrique habituel. Enfin, en bas deux courbes du gradient vertical. L'une est calculée en utilisant neuf cercles, l'autre six seulement. On voit bien que la différence est très faible. Par conséquent, pratiquement, il est inutile de dépasser six cercles, c'est-à-dire d'aller au-delà de cinq fois le coté a de la grille fondamentale (au lieu de dix fois).

Regardons, maintenant, un très curieux essai de double dérivée. Il est évident qu'au lieu de calculer directement la seconde dérivée, on peut calculer d'abord le gradient et, ensuite, dériver ce gradient encore une fois. On obtient ainsi une bonne vérification de nos formules. La figure 2 montre le résultat de cet essai. En haut est représentée une anomalie de Bouguer réellement rencontrée. L'une des deux courbes qui figurent en bas de la figure est la dérivée seconde calculée directement; l'autre courbe est la dérivée du gradient. La coïncidence des deux courbes est excellente.

Enfin, nous avons fait un essai, pour nous rendre compte du pouvoir séparateur du gradient vertical. Nous avons calculé le champ théorique g dû à trois sphères ou, si l'on veut, à trois points pesants, de même masse, disposés comme cela est indiqué sur la figure 3. A ce champ calculé, nous avons ajouté une très forte anomalie régionale affectant la forme d'un plan incliné. Le résultat est représenté en haut de la figure 3. On voit que les influences de trois sphères se trouvent confondues en une anomalie unique arrondie. La carte du milieu montre le champ de gradient calculé par la formule théorique exacte à une certaine profondeur que nous avons prise pour l'unité de longueur, les trois sphères étant placées à une profondeur égale à trois fois et demie cette unité. Sur cette seconde carte l'action de chaque sphère est visible séparément. Enfin, en bas de la figure 3 se trouve la carte du gradient calculé à l'aide de la formule approchée et en utilisant deux cercles seulement et la valeur à l'origine. Ces deux cartes, théorique et approchée, sont presque identiques. Elles ne diffèrent que d'une constante, d'ailleurs petite. Cette différence disparaît si l'on utilise neuf cercles.

Malheureusement, il n'est pas possible de donner ici des exemples pratiques complets, car la plupart des études sont encore en cours et les résultats appartiennent aux clients de la Compagnie Générale de Géophysique, qui voudra bien trouver ici les remerciements de l'auteur pour l'avoir autorisé à publier cet article.



Extrait de la Carte de l'Anomalie de Bouguer.
Part of the Bouguer Anomaly Map.

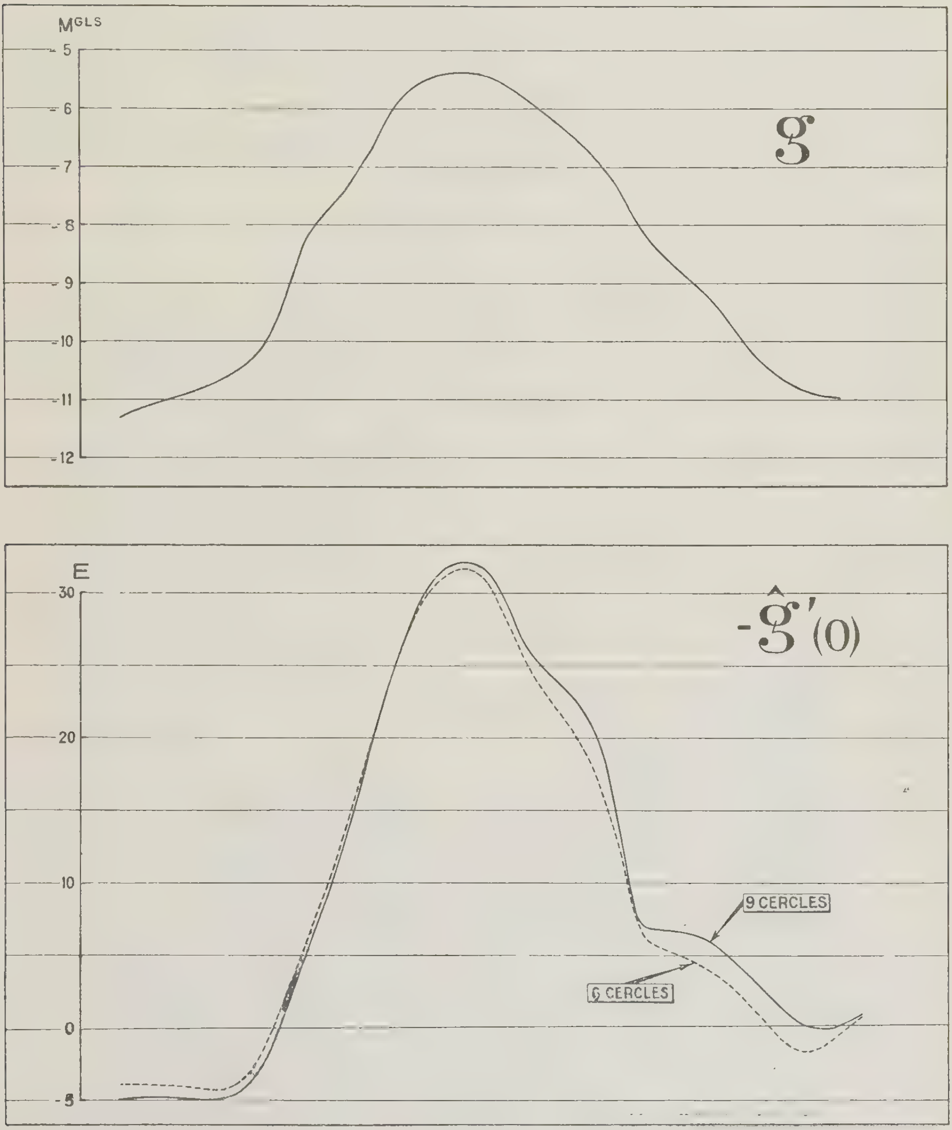
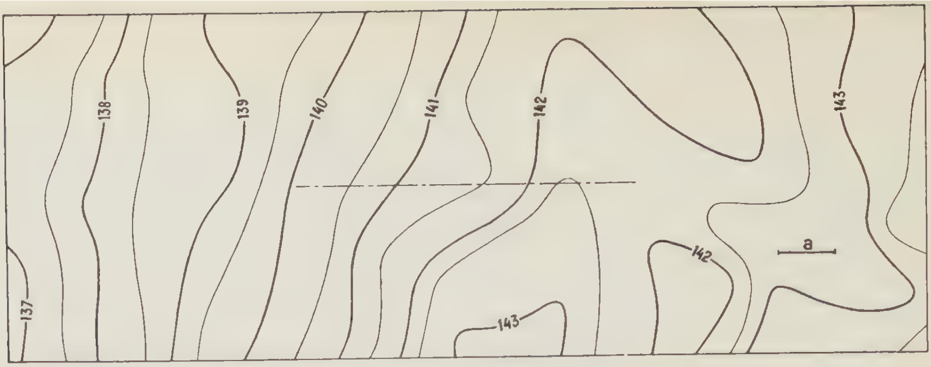


Fig. 1



Extrait de la Carte de l'Anomalie de Bouguer.
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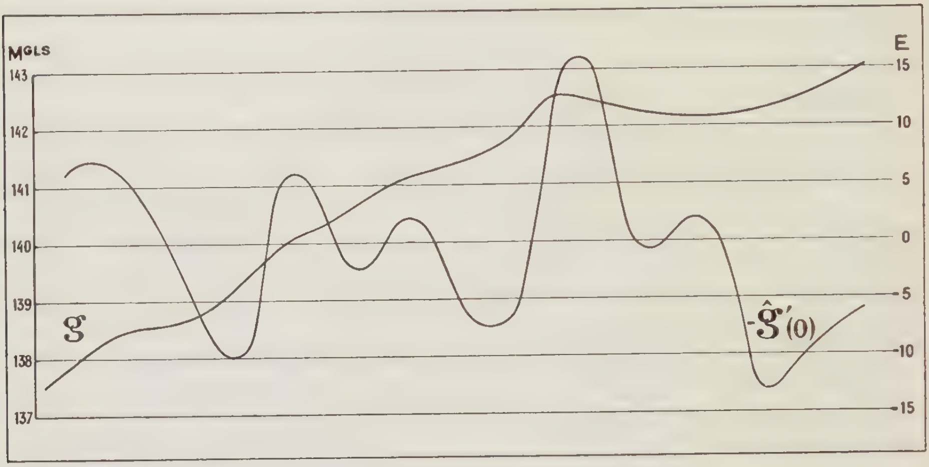


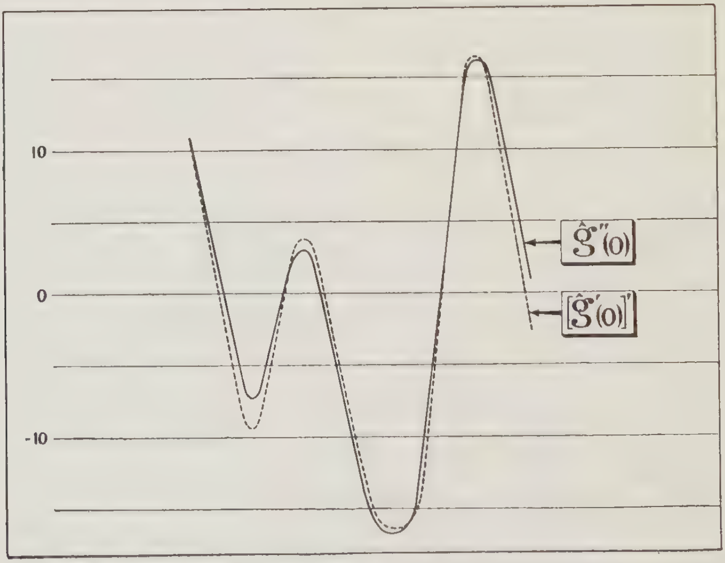
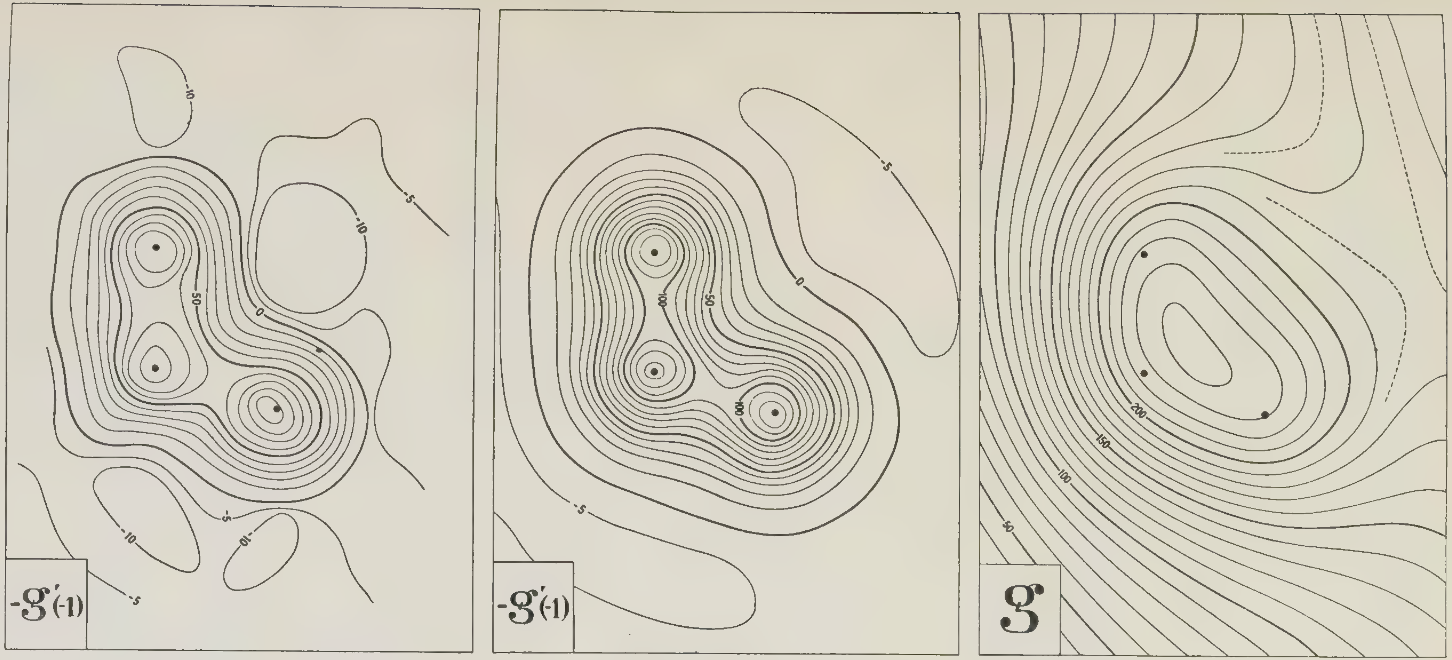


Fig. 2.



Champ du gradient calculé — Field of the calculated gradient.

Champ du gradient théorique — Field of the theoretical gradient.

Anomalie de Bouguer — Bouguer Anomaly.

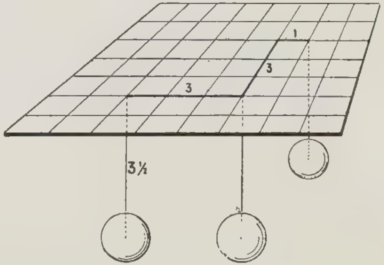


Fig. 3. Influence de 3 sphères — Influence of 3 spheres.

ANNEXE

Théorème I

Si la fonction intégrable $f(\rho)$ est continue à l'origine ($\rho = 0$) et bornée pour toute valeur de ρ, la fonction transformée

$$\hat{f}(z) = \int_0^{\infty} f(\rho) \frac{z \rho \, d\rho}{r^3} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

est continue pour $z = 0$ et sa valeur limite est $f(0)$.

En effet, soit ε un nombre positif donné aussi petit qu'on veut. La fonction $f(\rho)$ étant continue pour $\rho = 0$, on peut trouver un nombre positif η' tel que pour tout ρ inférieur à η' on ait

$$\left| f(\rho) - f(0) \right| < \frac{\varepsilon}{2}$$

D'autre part, il existe un nombre M tel que pour tout ρ

$$\left| f(\rho) - f(0) \right| < M$$

Dans ces conditions, on a

$$\hat{f}(z) - f(0) = \int_0^{\eta'} \left\{ f(\rho) - f(0) \right\} \frac{z \rho \, d\rho}{r^3} + \int_{\eta'}^{\infty} \left\{ f(\rho) - f(0) \right\} \frac{z \rho \, d\rho}{r^3}$$

d'où

$$\left| \hat{f}(z) - f(0) \right| < \frac{\varepsilon}{2} \int_0^{\eta'} \frac{z \rho \, d\rho}{r^3} + M \int_{\eta'}^{\infty} \frac{z \rho \, d\rho}{r^3} =$$

$$= \frac{\varepsilon}{2} \left(1 - \frac{z}{r_1} \right) + M \cdot \frac{z}{r_1} <$$

$$< \frac{\varepsilon}{2} + M \frac{z}{\eta'}$$

Pour rendre cette expression inférieure à ε, il suffit de prendre

$$\eta < \frac{\varepsilon}{2} \cdot \frac{\eta'}{M}$$

On aura

$$\left| \hat{f}(z) - f(0) \right| < \varepsilon$$

ce qui démontre le théorème.

Théorème II

Si la fonction intégrable $f(\rho)$ admet à l'origine une dérivée nulle remplissant une condition de Lipschitz, c'est-à-dire si

$$\left| f(\rho) - f(0) \right| < A \rho^2, \qquad \rho < \eta$$

(A fini quelconque)

et si elle est bornée pour tout ρ, la fonction transformée $f(z)$ admet une dérivée pour $z = 0$.

Posons

$$F(z) = \frac{\hat{f}(z) - \hat{f}(0)}{z} = \int_0^\infty \left\{ f(\rho) - f(0) \right\} \frac{\rho \, d\rho}{r^3}$$

Il faut évidemment démontrer que ε étant un nombre positif donné quelconque, on peut lui faire correspondre un petit nombre ζ tel que les conditions

$$z_1 < z_2 < \zeta$$

entraînent l'inégalité

$$\left| F(z_1) - F(z_2) \right| < \varepsilon$$

ce qui signifie que $F(z)$ tend uniformément vers une limite.

Nous avons, en effet

$$F(z_1) - F(z_2) = \int_0^\infty \left\{ f(\rho) - f(0) \right\} \left(\frac{\rho}{r_1^3} - \frac{\rho}{r_2^3} \right) d\rho$$

avec

$$r_1^2 = \rho^2 + z_1^2, \; r_2^2 = \rho^2 + z_2^2$$

En partageant l'intervalle $(0, \infty)$ en deux intervalles partiels $(0, \eta)$ et (η, ∞) on trouvera

$$\left| F(z_1) - F(z_2) \right| < A \int_0^\eta \left(\frac{\rho^3}{r_1^3} - \frac{\rho^3}{r_2^3} \right) d\rho + M \int_\eta^\infty \left(\frac{\rho}{r_1^3} - \frac{\rho}{r_2^3} \right) d\rho$$

ou, après avoir intégré

$$\left| F(z_1) - F(z_2) \right| < A \left\{ \frac{\eta^2 + 2 z_1^2}{\sqrt{\eta^2 + z_1^2}} - \frac{\eta^2 + 2 z_2^2}{\sqrt{\eta^2 + z_2^2}} + 2(z_2 - z_1) \right\}$$
$$+ M \left\{ \frac{1}{\sqrt{\eta^2 + z_1^2}} - \frac{1}{\sqrt{\eta^2 + z_2^2}} \right\}$$

Soit B un nombre au moins égal à A et à M. Alors, à fortiori, on a

$$\left| F(z_1) - F(z_2) \right| < B \left\{ u(z_1) - u(z_2) + 2(z_2 - z_1) \right\}$$

en posant

$$u(z) = \frac{\eta^2 + 1 + 2z^2}{\sqrt{\eta^2 + z^2}}$$

Cette fonction admet une dérivée négative pour η et z suffisamment petits, par exemple, pour

$$\eta^2 < \frac{1}{6} \text{ et } z^2 < \frac{1}{4}$$

Donc, u(z) décroissante et, par suite,

$$u(z_1) - u(z_2) < u(0) - u(\zeta) = \frac{\eta^2 + 1}{\eta} - \frac{\eta^2 + 1 + 2\zeta^2}{\sqrt{\eta^2 + \zeta^2}}$$

Renforçons encore en remplaçant $\sqrt{\eta^2 + \zeta^2}$ par $\eta + \zeta$. On verra que

$$u(z_1) - u(z_2) < \frac{\zeta(\eta^2 + 1 - 2\eta\zeta)}{\eta(\eta + \zeta)} < \frac{\eta^2 + 1}{\eta^2}\zeta$$

D'autre part,

$$2(z_2 - z_1) < 2\zeta$$

Donc,

$$\left| F(z_1) - F(z_2) \right| < B \cdot \frac{3\eta^2 + 1}{\eta^2}\zeta < \frac{3B}{2\eta^2}\zeta$$

Par conséquent, il suffit de prendre

$$\zeta < \frac{2\eta^2}{3B} \cdot \varepsilon$$

pour avoir

$$\left| F(z_1) - F(z_2) \right| < \varepsilon$$

pour tout z_1 et tout z_2 inférieurs à ζ.

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[1] H. A. EVJEN, "The Place of the Vertical Gradient in Gravitational Interpretations", Geophysics, Vol. I, No. 1, Jan. 1936.

[2] R. VAJK, "Regional Correction of Gravity Data", Geofis. Pura e Appl. Vol. XIX (1951) pp. 129-143.

DISCUSSION

Mr. ROSENBACH: Sie haben also den Parameter λ experimentell bestimmt?

Mr. BARANOV: Nous avons expérimenté avec les mêmes courbes. Je vous ai déjà dit tout à l'heure que, pour représenter la courbe dans le premier intervalle, c.-à-d. qui va de zéro jusqu'à A et de zéro à H, nous avons encore un point supplémentaire, $\sqrt{2}$, et un autre point, $\sqrt{5}$, mais qui se place en dehors de ces intervalles. Bien entendu, si je prends, par exemple, d'autres points, la courbe doit passer par ces points; mais son allure est influencée par la position des points.

Mr. ROSENBACH: Würden Sie nicht bei spitzeren Kurven ein anderes λ erhalten?

Mr. BARANOV: Non.

Mr. ROSENBACH: Es ist wunderbar, wie Herr Baranov aus diesem mathematischen Ausdruck, der ein uneigentliches Integral darstellt, etwas vernünftiges macht. Noch eine Frage: Sie müssen ja einen freien Randstreifen lassen?

Mr. BARANOV: C'est absolument exact. Si je prends 9 cercles p. ex., admettons que je peux calculer seulement au milieu. Nous avons reconnu que, 9 cercles, c'est un luxe; il suffit d'en prendre en tous cas 6 et donc, pour agrandir déjà ce centre, je diminue un petit peu les marges. Finalement, même 2 cercles suffisent.

Mr. ROSENBACH: Sie haben gerechnet bei den drei Kugeln $g'(-1)$. Wie lautet der Ausdruck für $g'(0)$?

Mr. BARANOV: Etant donné que l'anomalie est calculée à la surface, les 3 sphères ne séparent pas et, en utilisant 2 cercles, il n'y a qu'une petite incorrection.

A DEVICE FOR OVERCOMING THE EFFECTS OF STATIC ON SEISMIC SHOT SIGNALS *

BY

F. A. ROBERTS ** & A. T. DENNISON ***

Abstract

When refraction time signals are transmitted over a radio link between shooter and observer there is a serious risk of interference from electrical storms. This risk can be minimised by sending a series of signals at fixed time intervals and the paper describes a simple device which will do this with the required accuracy.

General Considerations

In refraction prospecting with distances of up to 20 miles between the shooter and observer, a radio link becomes essential for the transmission of the shot signal. This signal must have such a form that it gives on the record a clear indication of the instant of shot detonation. Systems of this nature have been used for many years, the three commonest types of signal being shown in Fig. 1. These are produced by

(a) switching a C.W. signal on or off at the shot instant

(b) switching on the modulation of an amplitude modulated transmission, and

(c) switching off the modulation of a similar transmission.

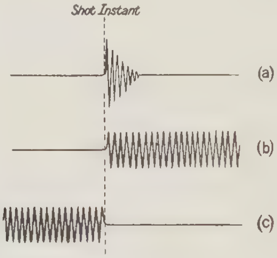

Fig. 1

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* Presented at the Hannover Meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

** Seismograph Service Ltd.

*** Anglo-Iranian Oil Company Ltd.

The relative merits of these systems will not be discussed here.

With each of these systems, considerable difficulties arise when radio interference is encountered. This interference is generally due to electrical storms, which may be particularly persistent in tropical regions, and it may completely mask the required shot signal or may so distort it that accurate measurement becomes impossible. Apart from the actual loss of time signals in this way, the possibility of such loss has often occasioned serious delays in field operations.

Some improvement can be obtained by adjustment of the audio-frequency response of the radio receiver but this is not sufficient in cases of strong interference and the alternative of using a telephone link is impracticable for long distance work. A modification of the signal system has therefore been devised which will give an accurate time signal even in very adverse conditions.

Essential Features

With this modified system, the explosion of the charge gives a shot signal of the usual form and this signal is then followed at regular intervals by a series of exactly similar ones (Fig. 2). If these signals occur at constant time intervals, the position of any one of them can be computed from the measured position of any two others. Thus if the first signal is obscured by interference, its position on the record can be accurately calculated provided only that its approximate position is known and that two of the subsequent signals can be measured. It is most unlikely that it would be impossible to measure at least two of the, say, thirty signals which would appear on a normal record.

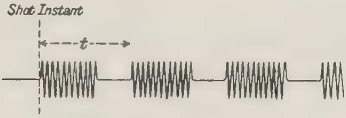

Fig. 2

Such a system must have the following features for it to be acceptable.

(a) The first pulse must indicate the instant of shot detonation with the same accuracy as the usual system. There is then no disadvantage in using the modified system in all conditions.

(b) Each signal must have a sharp front to form a good measuring point on the record.

(c) The time intervals between signals must be as constant as possible over a full record. Since the later signals are only measured in cases where there would normally be no measurable time signal, some variation over a five-second record may be tolerable but the accuracy should preferably be similar to that under (a). The long-term stability of the interval is of minor importance since the actual interval is measured on each record.

(d) The minimum interval depends on the accuracy with which the computer can estimate the position of a 'lost' time signal. Thus if he can estimate the position to ± 0.1 second, then an interval of 0.25 seconds will suffice to avoid the possibility of ambiguity. If it is considered that a signal will never be obliterated but only distorted, then the question of ambiguity does not arise and the time interval can be reduced. This point is of importance since the timing errors likely to arise are approximately proportional to the length of the time interval. A choice of intervals may therefore be desirable in a field instrument.

A Practical Circuit

The main difficulty in designing such a system is to ensure that the first and subsequent time intervals are identical. Whilst many forms of pulse generator are sufficiently stable in the free-running condition, the first cycle after the initiation of oscillation will usually differ somewhat from subsequent ones. There are doubtless many circuits which will overcome this difficulty but the one to be described forms a simple and compact unit which may be adapted fairly easily to suit most shot signal systems. The present form is designed for use with equipment where the transmitter modulation is switched on at the shot instant by the breaking of a link round an auxiliary detonator.

Basically, the system comprises a normal thyratron time base which is switched on by the breaking of the detonator link (Fig. 3a). The voltage (V_C) across the condenser and the current (i_R) in the resistor will have the form shown. It will be noted that the first and second cycles of the voltage waveform are not identical, the heights of the pulse fronts differing considerably. However, since the total length of this front may be reduced to say, 50 microseconds, any variations in this length will be negligible for the present purpose. The first and subsequent cycles of the current (i_R) waveform will therefore be effectively of equal length and can provide the required output signal. To a very close approximation, the total pulse length t is given by

$t = CR \log \left(\frac{E}{E - V_s}\right)$ where V_s is the thyratron striking voltage.

If the output of this time base controls the grid bias of a valve which also amplifies a 1,000 c/s signal, the anode current will have the waveform of Fig. 3(c). This may be readily shaped by a simple filter and used to drive the modulator stage of the transmitter. The signal received by the observer then has the form shown in Fig. 3(d).

Fig. 4 shows a self-contained modulator unit of this type built for field use. The thyratron output is fed through R_2 to the grid of V_3 which is normally biassed below cut-off. This grid is also fed with a small 1,000 c/s signal from the oscillator V_1V_2. When the detonator link is broken, the thyratron fires and the output then has the form shown in Fig. 3d. The 90 volt battery is contained within the unit and the 12 volt supply is taken from the transmitter battery.

Tests showed that with a pulse length of 0.25 seconds, the constancy of pulse length over a 5-second record was about ± 1 millisecond. This accuracy was considered adequate but it could perhaps be improved by stabilisation of the supply voltages with some consequent increase in complexity. Increase of the thyratron anode voltage will in general improve the accuracy and an appreciable improvement also results from the introduction of the cathode resistor in the thyratron circuit.

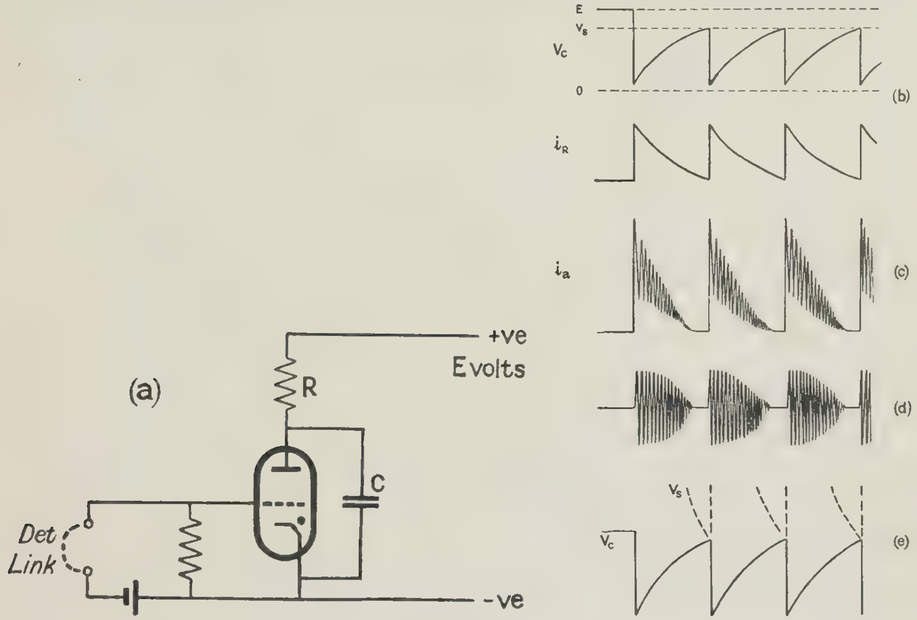

Fig. 3

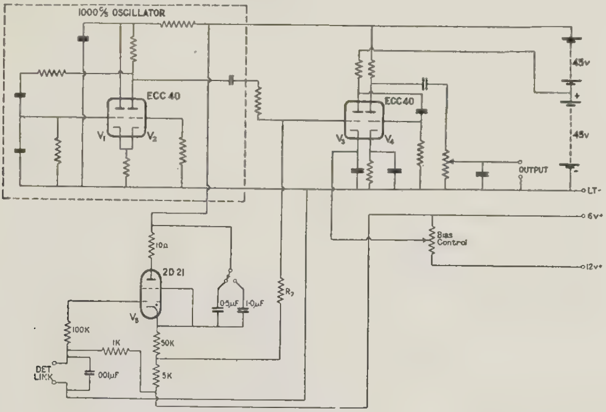

Fig. 4

This resistor may form the whole (as in Fig. 4) or part of the time constant resistance. During the cycle the grid-cathode voltage is then no longer constant and the striking voltage V_s will vary as shown in Fig. 3(e). The precise effects of this change will depend on the particular thyratron characteristics but in general it will give increased stability against variations in both supply voltages and the valve characteristic. The required CR value will be reduced and so the condenser size may be reduced by a factor of about four—an appreciable saving when a small unit is required.

As with all time-signal devices operating a high-power transmitter, care must be taken to minimise the pick-up of radio-frequency voltages in the leads since this may give distorted time signals and hence measuring errors. In conclusion it may be added that the circuit shown is intrinsically safe in that the maximum possible current in the detonator link circuit is 6 mA.

ACKNOWLEDGMENTS

The authors are indebted to the Chairman of the Anglo-Iranian Oil Company for permission to publish this paper and wish to acknowledge the helpful suggestions made by several of their colleagues during the development of the device.

THE APPLICATION OF RESISTIVITY METHODS IN ESTABLISHING THE BASE OF THE WATER-BEARING ROCKS IN THE CANNOCK CHASE COALFIELD *

BY

EDWARD JAN POLAK **

Abstract

In the Cannock Chase Coalfield the rocks of the overburden are heavily waterlogged, thus constituting a source of difficulty and even danger to the miner. In order to ensure maximum safety with the maximum use of reserves, the area has been investigated by boreholes and by resistivity surveys.

In this paper a short summary of the resistivity work is given, with especial reference to electrode arrangement and methods of interpretation used. Where applicable, comparison between resistivity evidence and borehole data is shown.

Introduction

With the development of the Cannock Chase Coalfield, mining operations have gradually extended northwards from the shallow exposed coalfield in the south first towards the central area covered by the Glacial Drift and later further north still, to the area covered by Triassic rocks (Fig. I). The rocks

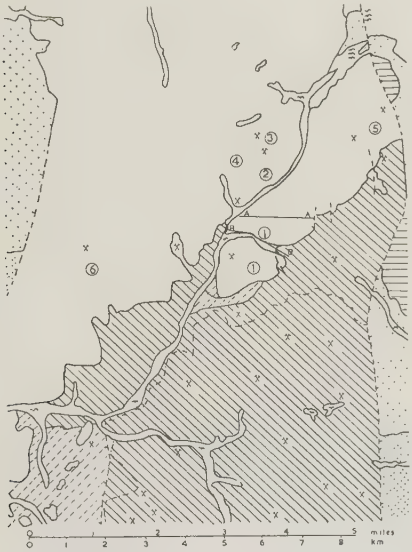

Fig. 1. Cannock Chase Coalfield

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* Presented at the Paris Meeting of the European Association of Exploration Geophysicists, May 20/22, 1953.

** National Coal Board, Cannock.

of the overburden are heavily waterlogged and thus constitute a source of difficulty and even danger to the miner. Therefore, in order to ensure maximum safety with maximum use of reserves, the area has been investigated by means of boreholes and, since 1948, by resistivity survey, so that an accurate map might be drawn of the base of the water-bearing rocks over approaching workings.

In this paper a short summary of the resistivity survey work is given, with especial reference to electrode arrangements and methods of interpretation. Where applicable, comparison is made between results obtained during the survey and those obtained from the borehole.

I. The Geology of the Area

The Productive Coal Measures consist of grey shales, sandstones, ironstones, fireclay and several coal-seams (up to 13 workable seams). The connate water in these measures is highly charged with salts.

By contrast, the Upper Coal Measures were deposited under semi-arid conditions compared with the warm and wet climatic conditions which obtained during the deposition of the Productive Coal Measures.

A series of subsequent earth-movements (late Variscan) distorted the structure to form horsts and graben, which were later eroded by waters flowing from mountains outside the area. This erosion was considerable, especially in the northern part of the coalfield, where all the coal seams were eroded, together with portions of the rocks below them. The resulting surface was uneven and cut by rivers, which deposited sand with occasional pebbles in the valleys to form the beds known locally as Littleworth Beds (Permian?).

In Triassic times the whole area was repeatedly flooded, resulting in the deposition of large boulders which attained a thickness of up to 250 ft. Upon these were deposited Lower Keuper Sandstone and Keuper Marl.

The pre-Glacial Alpine movement greatly affected the structure, breaking it by faults. Subsequent glaciation removed considerable sections of the strata filling depressions with glacial drift and Boulder Clay, up to 200 ft. thick.

II. The Electrical Characteristics of the Strata

(a) *The resistivity of the rocks*

The water of the overburden is fresh and contains only small amounts of salts. (It is widely used for the public water supply.) The porous rocks saturated by this high-resistivity water contrast with the low resistivity Productive Coal Measures filled with brackish water. Fresh water from the overburden penetrating the Coal Measures increases their original resistivity up to three times. This introduces complications in the interpretation of the resistivity curves, which give a hydrological rather than a geological boundary. Where the Productive Coal Measures are impervious the complication does not arise, as the actual base of the overburden corresponds with the hydrological boundary. These facts are well illustrated by the resistivity logs of the boreholes.

The following tables give the resistivity values of the rocks.

A. — In the Trias Area

I.	The Top soil and Aerated zone	30,000 — 15,000	ohm/cu.cm.
II.	Bunter Pebble Beds above the Water Table	200,000 — 55,000	„
III.	Bunter Pebble Beds below the Water Table	55,000 — 35,000	„
IV.	Littleworth Beds	22,000 — 17,000	„
V.	Productive Coal Measures (normally)	8,000 — 3,000	„
	„ „ „ (wet sandstones)	up to — 18,000	„

B. — In the Glacial Drift Area

Glacial Drift (sands) dry	— up to 27,000	ohm/cu.cm.
„ „ „ wet	— up to 12,000	„
Boulder Clay	5,000	„

Productive Coal Measures as in table A.

It was found that the resistivity of the Bunter Pebble Beds is not laterally constant, depending as it does on the ratios of boulders/gravel/sand. Narrow belts (sometimes only 200 ft. wide) filled with sand were of lower resistivity than boulder accumulations. This inconsistency hampered the application of constant spacing profiles and resistivity contour maps.

(b) *Electrical Anisotropy*

Anisotropy was found both in the Coal Measures and in the Bunter Pebble Beds. In the former, the conditions were typical of laminated sedimentary rocks of different resistivities. The anisotropy of the Bunter Pebble Beds is the result of the orientation of the elongated axis of the boulders depending upon the direction of the flood which deposited them.

III. THE SURVEY

(a) *Instruments*

Throughout the survey the instrument used was the Geophysical Megger Earth Tester manufactured by Evershed & Vignoles Ltd. London. Direct produced current generator incorporated in the instrument is commutated into A. C. and passes into the ground from two current electrodes. The drop in voltage between two potential electrodes is balanced by an opposing potential difference produced by the same generator. The ohmmeter reading depends on the ratio between this voltage drop to the current applied to the ground.

Certain readings were checked, using an Earth Resistivity Tester by the same maker. This was also used to measure the resistivities of very short spacings and of samples of water.

Stainless steel stakes were used for the electrodes.

(b) *Electrode Arrangement*

At the start of the survey the well known Wenner electrode configuration was used, checked by Lee Partitioning stations. Later on an asymmetrical electrode arrangement was adopted, the current electrodes being placed over 5,000 ft. apart with the line of the potential electrodes at an angle of up to 60° to them. It was concluded that this arrangement gave the quickest work and the best results in interpretation in general, other methods being used where especially applicable.

These included Jakosky's [1] method, which was used in two areas. This arrangement, which resembles Lee's to a certain extent, consists of five electrodes spaced "a" ft. apart. On stations placed across a buried pre-Triassic Valley it was possible to delineate the course of the valley from the difference in the shape of curves obtained by the following measurements:

a,	a,	2a,
a,	2a,	a,
2a,	a,	a,

Whatever the electrode arrangement used, distance between the electrodes was increased by steps of 20-30 ft. up to a distance of 1,000 ft. Thus for example, the total spread for the Wenner configuration was 3,000 ft. It was necessary for the steps to be as short as this in order to be able to smooth the curve and obviate effects from near the surface.

(c) *Background Information*

Fortunately, there was in practically every area of the survey an old borehole over which a set of six complete measurements was taken, using the Lee Partitioning method. The lines of the electrodes were placed at an angle of 60° to each other and a set of curves and the ellipsoid of anisotropy were drawn.

From the set of curves the following factors were deduced.

(a) The resistivity-ratio of the geological strata proved by the borehole.

(b) The anisotropy value, which showed the best electrode alignment to be adopted for the area near the borehole.

(c) The value of the correction required for "loss of depth of penetration".

In general, the curves were guide to the best method of interpretation to be adopted and the corrections to be made.

This preliminary information was supplemented by the analysis of water collected from every possible source in the area (boreholes, wells etc.).

IV. METHODS OF INTERPRETATION

(a) *Visual*

Certain curves show an abrupt change in the trend of resistivity at depths corresponding to boundaries between strata of different resistivities. This point of inflection, which changes according to the direction of the measurements, is most evident where measurements are taken along the long axis of anisotropy. The inflection is most clearly seen in the area where the Littleworth beds (Bed IV Table 1) are not present. The position of the point of inflection depends on the electrode arrangement. Using the four-electrode configuration in Area No. 4, where the spacing was 1.5a, 2a, 1.5a, the resulting apparent resistivity curve was similar in shape to the resistivity log of the borehole placed there, the point of inflection being at a depth corresponding with the base of the Trias.

It should be noted that caution is needed when visually interpreting these abrupt changes in the shape of the curve, as they may be the result of electrical discontinuity on the surface.

A characteristic feature of all the curves from one area was an increase in resistivity shown as a peak on the curve. This was found at depths corresponding to the thickness of the Trias and may be caused by the distortion of the electric field by underlying rocks of lower resistivities.

(b) *Superposition*

Curves obtained over boreholes were superimposed on the station curve. It was found that better results were obtained from the use of boreholes which had been recently drilled and electrically logged than from the use of old boreholes. In the case of the former, the depth of penetration of the fresh water into porous Carboniferous rocks has been proved and the geological interpretation checked; where the geological interpretation of an old borehole alone was used, however, the base of the Trias indicated by the resistivity survey was too deep, as the Etruria Marl beds had been wrongly assigned to the Trias.

It was found to be impracticable to use standard curves, as the number involved would have made the work of preparation too heavy, the problems being concerned with many layers of varying thicknesses and varying resistivity-ratios.

(c) *Mathematical Analysis*

A number of mathematical methods were used with success, although the simplifications inherent in the methods, such as the reduction of the problem to two layers, the assumption of electrical homogeneity and isotropy of the strata and of parallel beds would seem to suggest the introduction of inaccuracies in interpreting our complex conditions. Fortunately in practice, as the results showed, these methods were of value in interpretation when the necessary corrections were introduced to fit the circumstances.

In general the basis of the mathematical methods is the graphical solution of the problem by means of a set of curves evaluated from the formula of apparant resistivity based on the theory of images.

The following procedures were adopted:

TAGG [2]. In this method of interpretation the results were conditioned by the choice of a value for near surface resistivity. This was not easy, as it was necessary to approximate the resistivities of two layers, the lower one of which was characterised by linear decrease in resistivity with depth. It was therefore decided to use:

TAGG modified [3]. Here the apparent resistivity of a deeper section of the curve is chosen, thus avoiding the difficulty of disturbances from near the surface.

All the curves in the survey were subjected to this process, which was simple and quick to carry out.

All results were corrected for "loss of penetration", which was a value based either on evidence from the boreholes or on theoretical calculation. Where the beds were practically parallel and where the Littleworth beds were absent this correction was only 1,07 times, while for stations near the underground carboniferous bank the value of the correction reached its maximum value of 1.25.

This method was found to be of limited value where a thick stratum of Littleworth Beds is present in narrow carboniferous channels. Here there was no definite point of cross-section and attempts to force an interpretation produced results which proved to be too shallow.

PIRSON [4]. In this method the Tagg method is applied twice to multi-layer curves, first to locate the boundary between the top layer and the second and then of the third layer. In all the attempts to apply this method to our problems, the first layer could not be interpreted geologically, being probably the aerated zone. The second interface proved to be shallower than that deduced from the Tagg method. Thus the results did not justify the very much greater number of calculations required.

LONGACRE [5]. The results of this method were comparable with those of the Tagg modified method and many stations were subjected to this type of interpretation as a check to the Tagg modified method.

ROSENZWEIG [6]. In general the answer to the problem when this method was adopted depended upon the choice of the appropriate section of the curve. Where there was a check borehole and the section of the curve could be correctly correlated, the interpretation could be extended, so long as no great change in conditions occurred.

This method was used experimentally and was found to be of limited value in our conditions.

ROMAN [7]. Although it has been claimed for this method that it is by far the quickest, this was not borne out by our experience, in view of the necessity of drawing both arithmetic and logarithmic curves. Also the steep curve which resulted from a high value for "k" (approaching 1) made matching the curve difficult. Further, the high ratios of the two resistivities gave the bottom layer resistivity as "perfect conductor", so that the check in interpretation normally given by the lower bed resistivity was not available.

(d) *Other Methods*

Moore [8]. This is a very controversial method, which is of great help under certain conditions. It was found to be particularly useful in the Glacial Drift Area, where the channels in the resistive Coal Measures are filled by lower resistivity wet glacial sands and clays. In the line of electrodes placed across a channel the first deflection indicated the edge of the channel and the second the bottom of the valley.

V. The Results

As may be seen from the above discussion on the methods of interpretation used, there was no method which could be applied without discrimination to every part of the area. As the survey extended it was possible to apply the appropriate method with more certainty, although new problems were constantly appearing.

The most successful application of the resistivity method was in Area No. 4. Here the Bunter Pebble Beds overlie a very thin stratum of Littleworth Beds, all resting on Productive Coal Measures. The whole area was treated as a twolayer problem and the results were proved by subsequent boreholes. All the results were interpreted according to Tagg's modified method.

	Depth Borehole	Water Penetration Elec. Logs	Depth Res. Survey	Difference ft.
High Oak	223	237	246	9
Brindley Valley	223	223	230	7
White House "A"	218	218	220	2
"B"	215	220	220	0
"C"	212	no log	220	8
"D"	205	205	215	10
"E"	215	215	217	2

As the area extended westwards across a major fault, reliance on geological evidence from old boreholes, drilled more than 80 years ago, gave the wrong basis for the interpretation of the resistivity data. This was due to the inclusion of a section of Etruria Marl in the Trias.

The geological evidence of two boreholes was reconsidered as follows:

	1st Interpretation	Reconsidered	Resistivity
Fair Oak Tree	400	330	330
Sherbrook Valley	225	135	122

Further west still, at the Broadhurst Borehole, the base of the Trias was found at 160 feet, the base of the Etruria Marl at 240 ft. as against 246 ft. in the resistivity survey.

In area No. 5 the Tagg Modified Method was used. There is a thin layer of Littleworth Beds.

	Thicknes of Trias		Difference
	Borehole	Res. Survey	
Regents Wood	76	85	9
Lower Cliff	228	230	2

In area No. 2 conditions were much more difficult. A steep Carboniferous embankment is covered by Triassic rocks, the surface of the Coal Measures being very uneven. Tagg Modified and Roman Logarithmic methods of interpretations were used, with a correction factor varying from 1.07 to 1.25 over the carboniferous slope (gradient approximately 1 in 2). Four boreholes were put down to check the results.

Base of the Unconsolidated Rocks (in feet)

	Borehole	Res. Survey	Difference
Moors Gorse (F)	225	230	5
„ „ (H)	254	270	16
„ „ (J)	237	249	12
„ „ (K)	245	245	0

Two boreholes (H, J) proved that the top of the coal measures is weathered to a depth of 20 ft.

Area No. 1 (Fig. 2) provided even more difficult conditions. In a valley resulting from faults, a flat blanket of Bunter Pebble Beds was deposited, covering a narrow gorge filled with Littleworth Beds. The difficulty was increased by the surface terrain. All the curves were interpreted according to Tagg's method with the Longacre Method as a check.

The deepest part of the valley was re-surveyed, using Jakosky's electrode arrangement in order to obtain the line of the buried gorge. The Tagg modified method was then used, but the results were still too shallow.

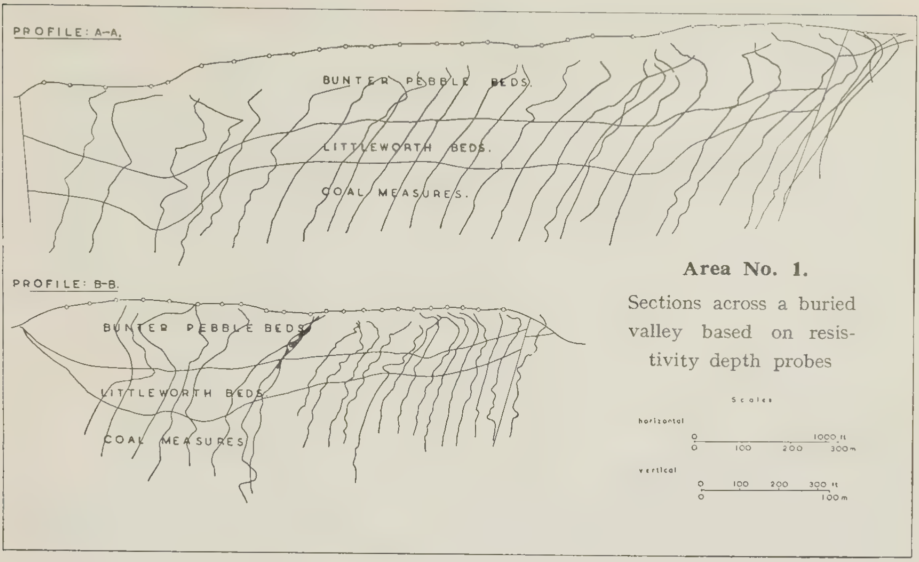
The following table shows the comparison between the borehole results and resistivity results.

	Borehole	Res. Survey
Bentley Brook *	256	156 (Bunter Pebble Beds to 156 ft.)
Pool Pit No. 1	99	108
„ „ No. 2	125	125
„ „ No. 3	230	202
„ „ No. 4	310	230

* The first borehole put down to prove the resistivity survey.

Similar conditions prevailed in Area No. 6a:

	Thickness of Trias	
	Borehole	Res. Survey
White Lion	270	280
Cavans Cottages 1	310	280
„ „ 2	190	140



Area No. 1.
Sections across a buried valley based on resistivity depth probes

Fig. 2.

It should be pointed out that the main use of a resistivity survey in these areas, where accurate interpretation proves impossible, is that an indication is given of where the deepest part of the area is, so that a borehole may be sited there.

An extensive survey was carried out over the part of the coalfield covered by Glacial Drift. It is difficult to judge the results, as the boundary between the fresh and brackish water very seldom corresponds to the geological boundary. The rocks at present covered by glacial drift, before subjected to the action of ice (pressure and temperature), differ greatly in compactness, porosity and strength from the same rocks protected by the Triassic blanket. Fresh water penetrates very easily, the depth of penetration being shown by the resistivity results.

The survey was carried out on the same lines as over the Bunter Pebble Beds, except that the stations were spaced much more closely (no more than 90 ft. apart).

When interpreting the results the W. Moore cumulative method was used with marked success, especially where a narrow pre-glacial valley was buried by glacial deposits. In this case the second inflection of the curve corresponded closely to the thickness of the drift, the first inflection being the edge of the valley. This method was limited in its application to curves obtained in low-lying fields partially covered by water. Where the water table lies some distance below the surface the Tagg modified method was used, supported by the Longacre and Roman superposition methods. There was no need to introduce corrections, as the resistivity of the Coal Measure beds full of fresh water equals that of the glacial sands.

The following three tables show the results obtained in the resistivity survey, checked by subsequent boreholes.

A. The results agree closely.

		Borehole	Res. Survey	Difference
New Hall	No. 3	95	96	1
	5	65	69	4
	7A	75	78	3
	8	65	68	3
	18	83	83	0
	23	85	93	8
	24	70	70	0
Leacroft	No. 4	44	55	11
	5	53	60	7
	6	66	65	1
	7	56	55	1
Gains Plantation	No. 12	100	99	1
		95	110	15

B. Resistivity Survey indications deeper than the boreholes (Fresh Water proved in Coal Measures).

	Borehole	Res. Survey	Difference
New Hall No. 13	67	115	48
Gains Plantation No. 15	63	97	34
No. 16	56	70	14

C. Resistivity Survey results too shallow.

	Borehole	Res. Survey	Difference
New Hall No. 7	90	75	15

VI. CONCLUSION

As is clear from the results, the geophysical resistivity method provides a valuable adjunct to the geological evidence. Boreholes and geophysical work must be treated as complementary. It is doubtful whether one of the methods by itself could prove itself to guarantee complete safety for mining under water-bearing rocks in conditions similar to those in the Cannock Chase.

Even in those cases where the resistivity method provides no quantitative interpretation, qualitative information for placing boreholes is given.

ACKNOWLEDGEMENT

I am indebted to Dr. J. Smillie, Area General Manager, No. 2. Cannock Chase Area, National Coal Board, for permission to use the data.

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Discussion

Mr. Le Masne: What surprises me is the very good precision claimed in depth to bed-rock determination (about 3%, I understand). I imagine this is due to the fact that both resistivity and thickness are fairly constant in the area surveyed and formations remarkably homogeneous. I would like also to ask Mr. Polak whether such accurate results can be obtained in every instance or if they are rather exceptional.

Mr. Polak: A number of boreholes and resistivity logging measurements backed up our knowledge. Perhaps I was very fortunate, but our indication proved very good. In the strata overlying the Coal measures resistivity actually varies from 20,000 to 55,000 according to logging of boreholes.

Mr. Breusse: Mr. Polak tells us that the sections where coal measures resistivity is the highest are water flooded sections. I am rather surprised at this conclusion for, generally, the reverse phenomenon would occur. So, I would like to know what is the resistivity of water?

Mr. Polak: This resistivity has been measured and is very high for it deals with very pure water.

Mr. Breusse: The risistivity of water reaches very seldom more than 10.000 ohms-cm and then it has to be extremely pure water flowing through very clean quartz sands.

Most generally, water resistivity varies from 1,500 to 5,000 ohms-cm. But the resistivity of the coal measures varies from 20,000 to 50,000. It is therefore difficult to explain how an addition of a smaller resistivity water may increase this of the whole.

I am surprised too of the similitude between the electrical sounding and the electrical coring diagrams. One may ask whether the sharp variations of apparent resistivity to be seen on electrical loggings are not more probably correlated with perturbations brought in by superficial heterogeneities of the ground.

Mr. Polak: Sometimes may be, but, generally, variations of the resistivity obtained on the surface coincide well with those recorded by electrical coring.

APPLICATION OF VERTICAL GRADIENTS AND COMPARISON OF DIFFERENT GEOPHYSICAL METHODS IN A DIFFICULT AREA [*]

BY

A. M. SELEM [**] AND C. MONNET [**]

Abstract

Seismic reflection, telluric and gravity results are given for the lifted area of Ferrara, in Northern Italy. The agreement is shown between the available shallow seismic data and the gravity evidences. For a portion of the above area where seismic results are particularly poor the vertical gradients method gives a resolution of a gravity anomaly and confirms the telluric information. The residual gravity values, the vertical gradients and the telluric data along a seismic line crossing the zone are compared with seismic results and with evidences from adjacent wells.

This paper deals with the portion of the Eastern Po Valley around Ferrara where the Tertiary and the Mesozoic formations show a general uplift between the pre-Apenninic trough and the pre-Alpine monocline. Figures 1 and 2 are showing the extension of the above area.

The wells which were drilled in the area prove that the formations underneath the thin Quaternary cover are mostly of the Middle and Lower Pliocene and in several places of the Miocene, whilst the well at Vincenza Nuova met the Senonian limestone at a depth of about 1500 metres.

Tectonically the lifted area of Ferrara is affected by many faults and displacements and stratigraphycally there are also several unconformities.

The uplift of Ferrara was discovered in 1933 by an Eötvös balance broad reconnaissance survey. Later on, in 1950, the area was surveyed by a crew of the Compagnie Générale de Géophysique with the telluric method and in 1951 the seismic reflection method was tried along lines of broad exploration.

The results of the telluric method being mainly based on the raising of the limestone formations, this survey was only able to locate the more lifted areas but did not reach the necessary details. Evidence of this may be seen in Fig. 2 where the telluric results are compared with the data shown by the seismic survey with particular regard to the more shallow trends.

However, due to the structural complexity of the formations underneath the Quaternary cover, the seismic response is generally very poor and in some

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[*] Presented at the Paris Meeting of the European Association of Exploration Geophysicists, May 20/22, 1953.

[**] Azienda Generale Italiana Petroli.

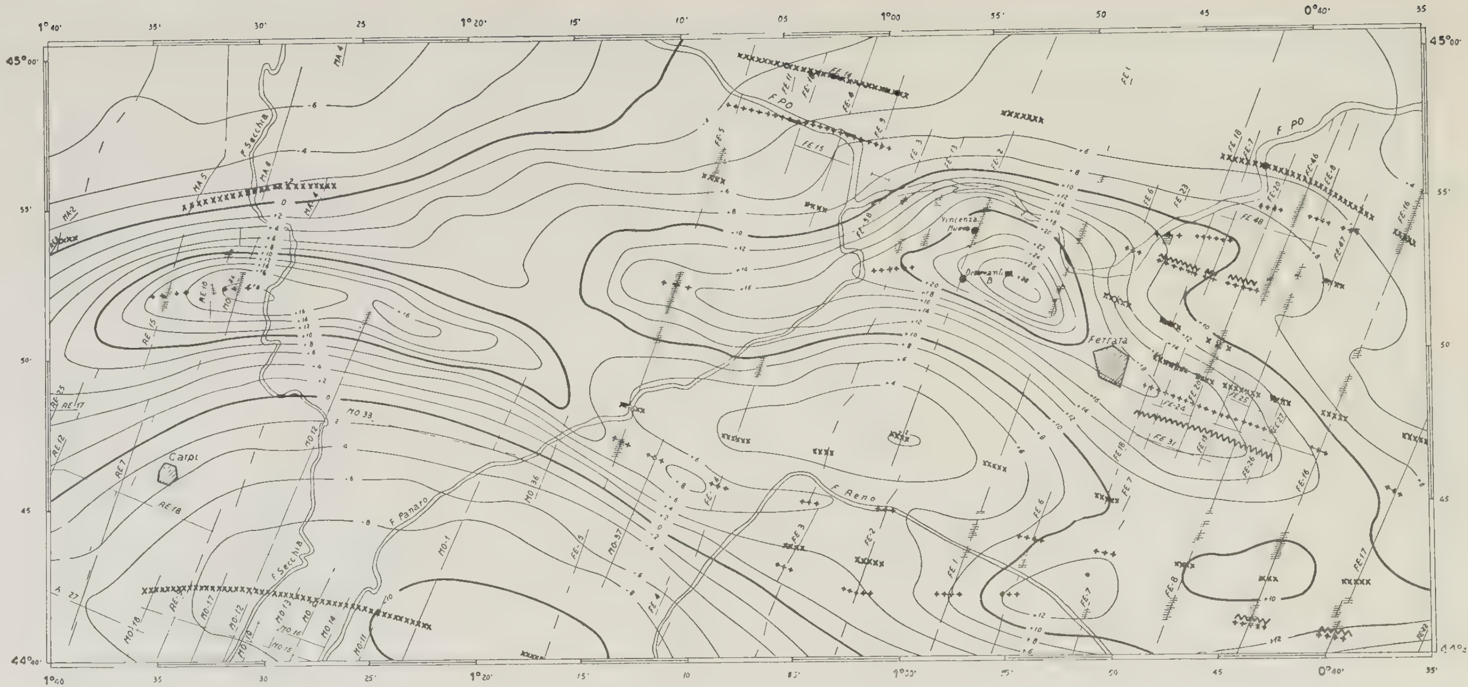

Fig. 1. Area of Ferrara uplift. Residual anomalies and seismic results. Approx. Scale 1 : 475 000

Contour interval for residual anomalies 2 mgals.

≡ Zones of poor or nul seismic response.
+++ Anticlinal trend by seismic data.
xxx Sinclinal trend by seismic data.
∿∿ Fault by seismic data.

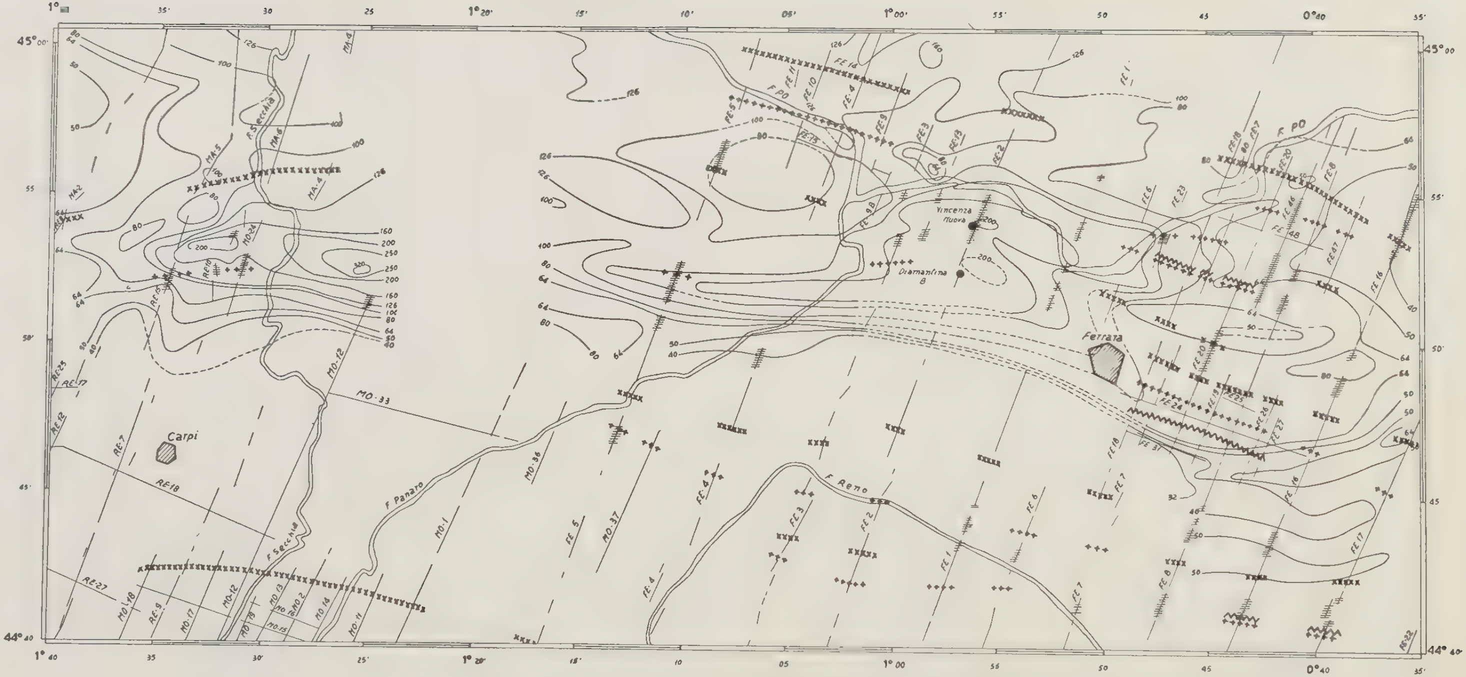

Fig. 2. Area of Ferrara uplift. Telluric survey and seismic results. Approx. Scale 1 : 475 000

160 ⁀ Contour curve of equal ellipse area.
▤ Zones of poor or nul seismic response.
+++ Anticlinal trend by seismic data.
xxx Sinclinal trend by seismic data.
〰 Fault by seismic data.

portions of the area particularly on the highs is practically nil. Comparisons between the poor seismic response in the Ferrara area and the better results in the adjacent zones are shown on Figures 3 and 4.

Therefore the seismic survey made only possible to follow the main anticlinal and sinclinal trends through the area, but the data available do not allow any definite contouring.

It was consequently decided to cover the whole area with a detailed gravimeter survey. The decision was made on the assumption that the shallow formations of the Tertiary and of the Cretaceous would influence the gravimeter measurements with satisfactory evidence.

From the Eötvös balance survey and from Morelli's results [1] it was already known that the area was affected by an exceptionally strong regional gradient. In fact, Bouguer's anomalies vary from — 150 mgals along the Apenninic border (Reggio area) up to +30 mgals on the Euganei Hills, over a distance of about 100 Kms.

The interpretation of the area by a gravimeter survey was therefore only possible provided the regional correction would have been carefully determined. This was done using the regional gravity data already known and calculating the regional anomaly with the average profile method. A general increase from SW to NE was found, with very high gradients everywhere which in some places reach values of 24 Eötvös.

Figure 1 shows the residual anomalies which were obtained. For the central lifted portion of the area the agreement between the residual anomalies and the trends outlined by the seismic survey is quite good. Also in good concordance are seismic and gravity results on the Southern flank of the Ferrara uplift, whilst on its Northern flank the gravity axes—if compared with the seismic trends—are displaced to the North. This however is connected with the side influence of the disturbing body represented by the whole of the Ferrara uplift and with the smaller depth of its Northern trough.

In consideration of the good agreement between the above gravity results and the seismic information the attention was focused on the areas of gravity highs. On some of those highs no further interpretation was possible because of the very poor seismic results and other ways of resolving the residual anomalies were therefore necessary. This could be attempted by using the methods of the vertical gradients and of the second derivatives.

The vertical gradients proved to give a more realistic picture of the situation, as it had to be expected.

Figures 5, 6 and 7 represent the area of a gravity high to the North-West of Ferrara.

Together with the seismic information, the results of the telluric survey are shown (Fig. 5), the residual anomalies are mapped (Fig. 6) and the distribution of the vertical gradients is given (Fig. 7).

The particular shape of the residual anomaly (Fig. 6) allowed for the possibility of more than one high in the zone. This was already suggested by

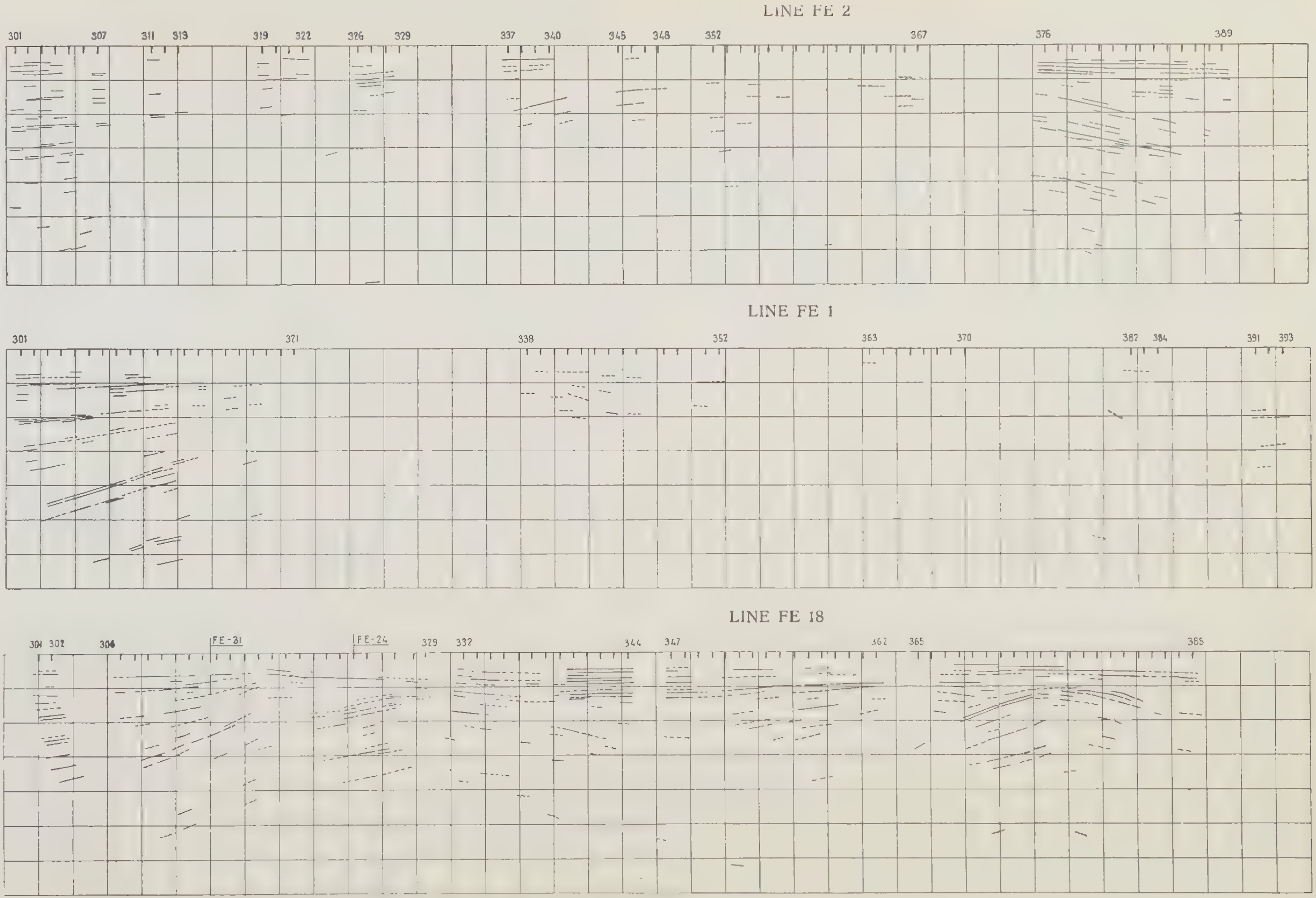

Fig. 3. Seismic response in the area of Ferrara uplift. Approx. Scale 1 : 100 000

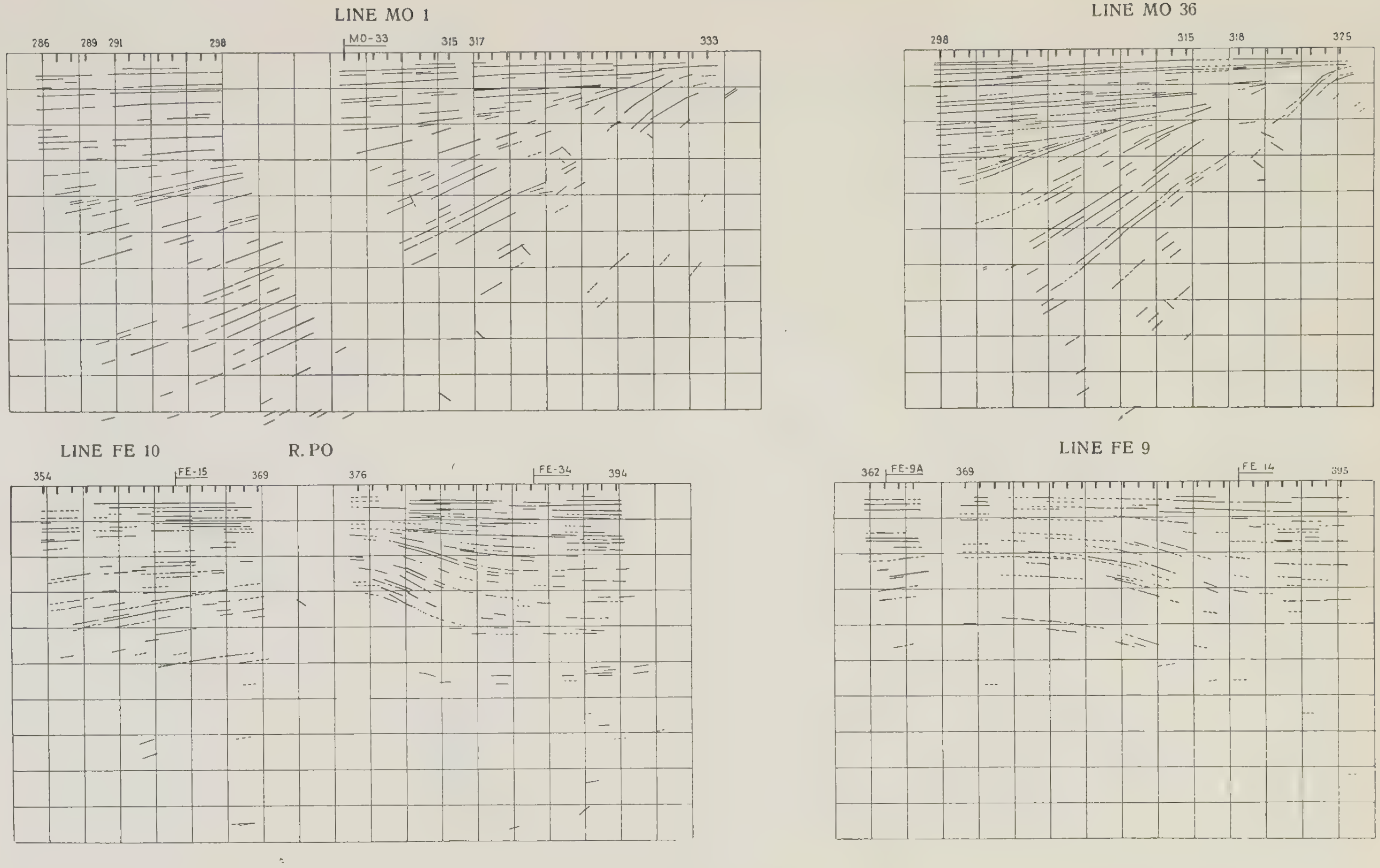

Fig. 4. Seismic response in areas adjacent to the Ferrara uplift. Approx. Scale 1 : 100 000

the telluric results but a further prove of it was wanted. The vertical gradients method was therefore used.

The values of Bouguer's anomalies were considered and Baranov's formula was applied [2]. A grid of 1,2 Kms. spacing was used and the calculations were extended to six circles around each point of the grid.

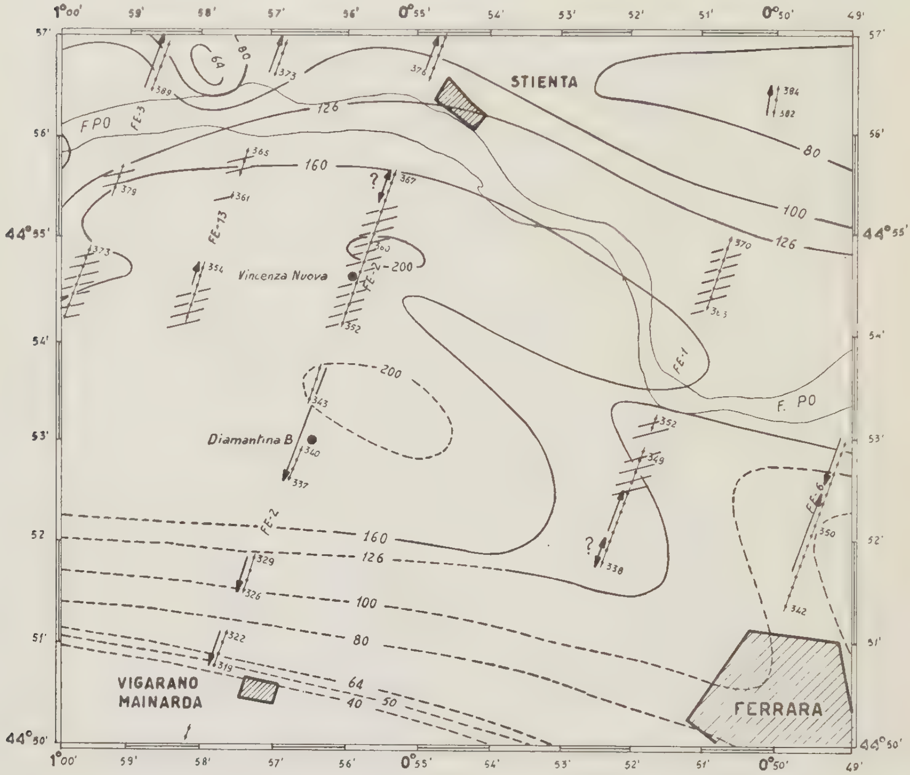

Fig. 5. Area NW of Ferrara. Telluric survey and seismic information.
Approx. Scale 1 : 145 000

160 —— Contour curve of equal ellipse area,
//// Poor or nul seismic response.
← Dip from seismic results.

So doing the area necessary for the calculations extended beyond the area of the interpretation for a surrounding strip 6 Kms. wide. The calculations were therefore limited to the first seven terms of Baranov's formula and for the last three terms values of average anomalies were assumed which were equal to the ones of the circle of 6 Kms. radius.

The map of the vertical gradients was consequently obtained, as it is shown in Fig. 7. The vertical gradients resolve the residual anomaly of Fig. 6 into two maxima, respectively to the N-W of Ferrara (maximum of Diamantina) and to the S-W of Stienta (maximum of Vincenza Nuova). These two maxima confirm the telluric indications, although the location of the second telluric high remains questionable as it will be said further on.

Figure 8 shows a cross section of the seismic line FE-2 where all the above results are plotted and the stratigraphic data of the two adjacent wells of Diamantina B. and of Vincenza Nuova are also marked. Under Shot Points 345-348 the curve of the telluric data and the curves of the residual anomalies and of the vertical gradients show all a peak and the agreement between them is very satisfactory.

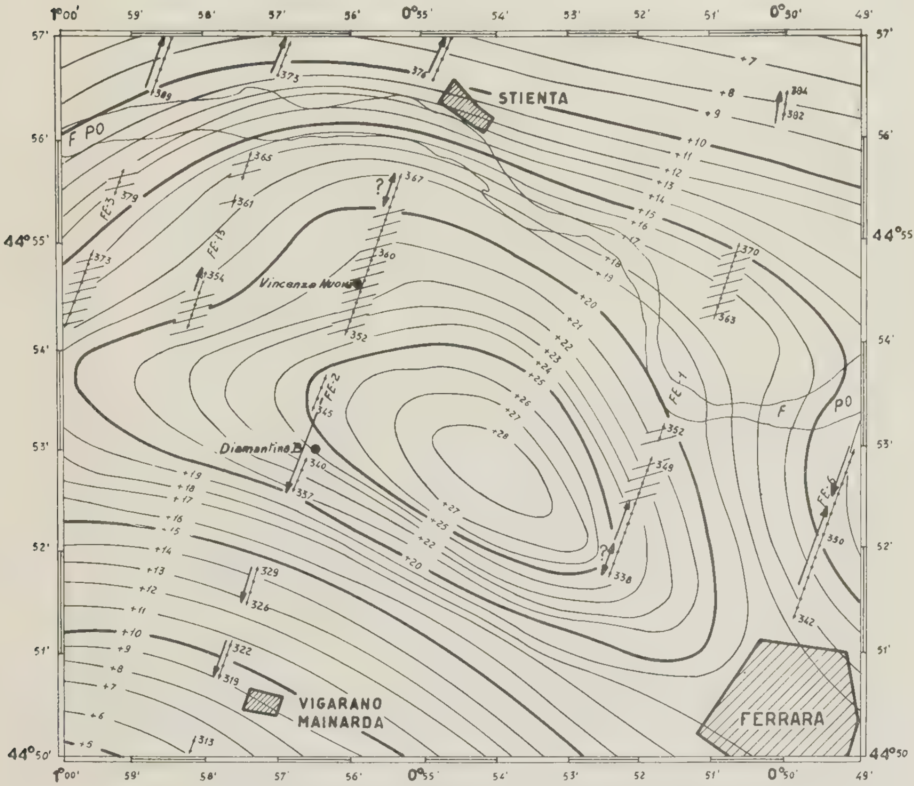

Fig. 6. Area NW of Ferrara. Residual anomalies and seismic information. Approx. Scale 1 : 145 000.

Residual anomalies contour interval 1 mgal.

//// Poor or nul seismic response.
← Dip from seismic results.

Further to the N-E where the decrease of the residual anomaly becomes more gentle a second peak appears both for the telluric curve and for the vertical gradients. The two peaks however do not occur at the same point but the distance between them is of about 1,3 Kms.

The agreement between the peaks underneath Shot Points 345-348 and the data from the wells of Diamantina B. and of Vincenza Nuova is very impressive.

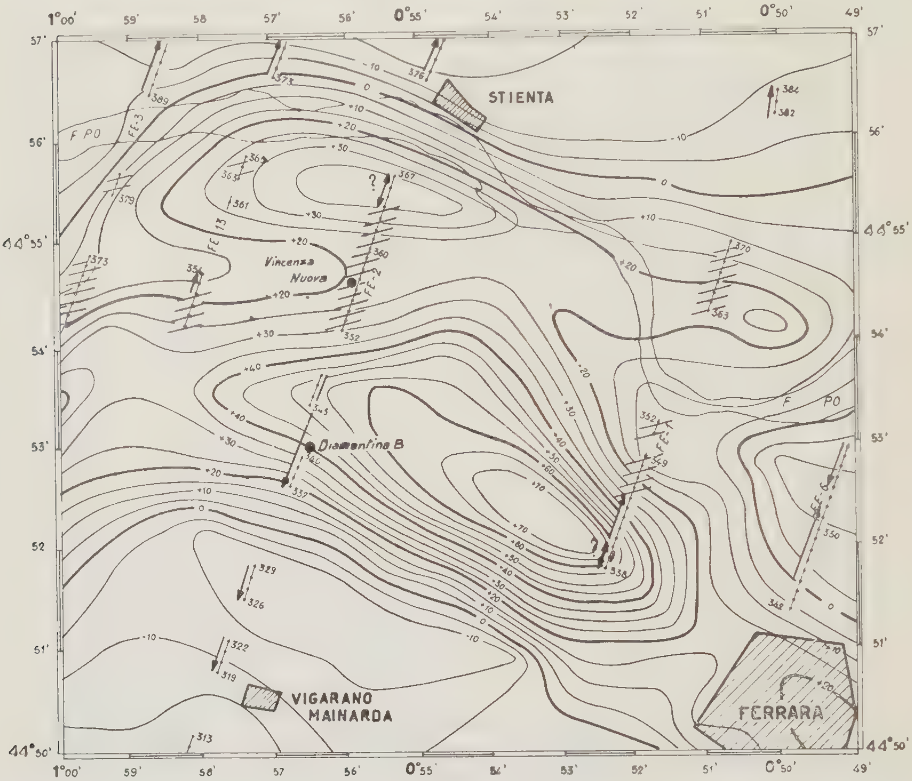

Fig. 7. Area NW of Ferrara. Vertical gradients and seismic information. Approx. Scale 1 : 145 000.

Vertical gradients contour interval 5 Eötvös.

//// Poor or nul seismic response.
← Dip from seismic results.

At the well of Diamantina B. the Quaternary cover has a thickness of 165 metres, it is then followed by 195 metres of formations of the Langhian-Aquitan, and at a depth of 360 metres the Oligocene is found. At the well of Vincenza Nuova the Quaternary cover is 160 metres thick and it is followed by 460 metres of formations which for the higher sections are estimated to

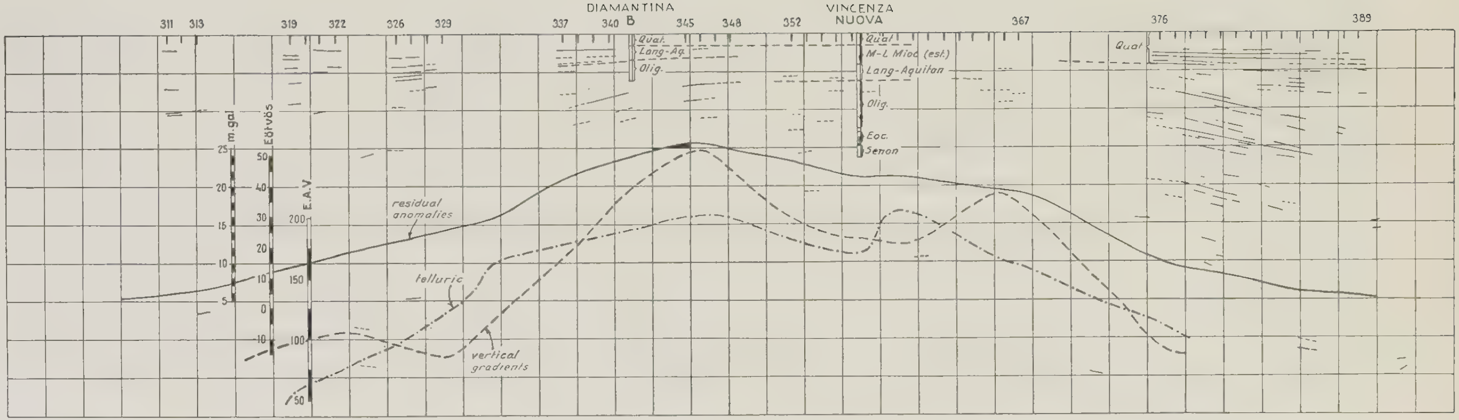

Fig. 8. Cross-section of line FE-2 between Vigarano Mainarda and Stienta with curves of residual anomalies, vertical gradients and telluric E. A. V. and wells of Diamantina B. and of Vincenza Nuova.

Approx. scale 1 : 100.000

be of the Middle and Lower Miocene and for the lower sections are surely of the Langhian-Aquitan. The top of the Oligocene is found at a depth of 620 metres. The smaller thickness of the Miocene at Diamantina B. and the greater depth of the Oligocenic top at Vincenza Nuova, if compared with the continuous raising of the seismic data between Shot Points 337-348 and 352-358, may be explained only by admitting the existence of a fault between Shot Points 348-352 which lowers towards the North the formations up to the Miocene. The first peak of the telluric curve and the first peak of the vertical gradients are consequently explained.

This clear agreement among all the data available for the area between the wells of Diamantina B. and of Vincenza Nuova allows for the presumption of another structural high where the vertical gradients or the telluric curve show their second peak. It is not known how this second high is originated but it may be assumed that the pre-Quaternary formations become deeper only North of Shot Point 367. In fact under Shot Points 363-367 the seismic picture seems to be quiet and only North of Shot Point 367 the gravity values accentuate their decrease. The sudden thickening of the Quaternary cover North of Shot Point 367 proves that the pre-Quaternary formations have become deeper there and this may be caused either by fault or by erosion. Anyway, whatever may be the cause of the above deepening, it seems more reliable to locate it North of the second peak of the vertical gradients than near the second peak of the telluric values. This since the deepening pre-Quaternary beds are still fairly shallow and have necessarily to influence the vertical gradients, whilst the telluric data are based mainly on the effects of the deeper limestone. Besides that the gravity station density is much higher than that one of the telluric stations.

The above results are shown because in areas particularly difficult for the geophysical exploration the comparison of results from different methods may lead to conclusions which allow for a more satisfactory interpretation of the structural situations and because, in proper conditions, a detailed gravimeter survey and the careful use of the vertical gradients method may give useful resolution of complicated gravity anomalies.

Acknowledgments

Appreciation is expressed to Dr. T. Rocco for his encouragement and criticism and to the officials of the Azienda Generale Italiana Petroli for the permission to publish the geophysical results of above.

Literature

[1] C. Morelli, "Rilievo gravimetrico e riduzione isostatica nell'Italia Nord-Orientale", Tecnica Italiana 1951, N. 3 e 4.

[2] V. Baranov, "Calcul du Gradient Vertical du Champ du Gravité ou du Champ Magnétique, mesuré à la surface du Sol", Geophysical Prospecting 1953, Vol. 1, No. 3.

Discussion

Mr. Germain-Jones: This comparison of different methods is a very good idea. I would like to ask for a slight indication of the types of Miocene, Oligocene and older formations.

Mr. Selem: Tertiary formations are mainly marles, clays and sands. The Secondary is mainly of limestone character. At Vincenza Nuova a kind of broken pinky limestone (scaglia rosata) was found which reappears in the Veneto. The seismic response from this formation is remarkably poor and often nil.

Mr. Germain-Jones: Have you tried refraction?

Mr. Selem: We did not try refraction methods because we think the formations above and also in the limestone may be very broken and complicated. The investigation of the area is not completed. For the moment we are just interested in the general outline of the structure, but we plan to try refraction.

Mr. Germain-Jones: I could not help thinking that by using up and down shooting you could perhaps get an indication of the faults.

Mr. Selem: I myself tried this in other areas.

This area is just under exploration at present, some further investigation will be carried out.

Mr. Germain-Jones: I shall be very interested to know these results when you get across that structure.

Mr. Richards: Would like to know what velocity-distribution has been used.

Mr. Selem: We used the same velocity-distribution which has been chosen for the rest of the Po Valley. From several well shooting tests spread through the whole of the Po Valley this velocity-distribution has been found correct with a maximum error of 3 to 4%. However no velocity tests were done in the area of the Ferrara uplift and the disagreement there could be greater because of the raising of the older formations. But for the shallower beds the correction for the spread length has been checked and the velocity-distribution we used proved to be in agreement with the actual velocity there.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

111. *New Exploration Methods have a Great Future but need Support.*
Engng. & Min. J., Vol. 152, No. 7, pp. 88-91, 1951.
Urgent plea for the financial support of new geophysical methods by mining executives in order to assure mineral supplies for the future. Cites some examples of airborne magnetometer and electromagnetic surveys of ground magnetic, electrical, and seismic work and of the potential-decay method.

112. *Electrical and Magnetic Prospecting in the Sankyo Iron Mine, Nügata Prefecture.* (In Japanese with English summary).
J. Kaneko, Bull. Geol. Surv. Japan, Vol. 2, No. 7, pp. 38-43, 1951.
The ore is a contact metamorphic deposit accompanied with micaceous hematites, magnetites, and pyrites. Electrical and magnetic prospecting methods are practised in Kayaba-sawa area and Okamosukesawa area. Judging from negative S. P. anomalies and vertical magnetic anomalies, places for core drilling are recommended.

113. *The Development of Geophysical Methods of Exploration in Germany since 1945.* (In Spanish).
R. H. Gees, Rev. Geofis., Vol. 10, No. 39, pp. 180-207, 1951.
Geophysical exploration in northwestern Germany is reviewed. Gravity, magnetic, seismic, and electrical methods were employed; mostly in the search for oil. In prospecting for sweet water on the islands of North Sea, differences in the specific resistivity of strata containing salt water and strata containing sweet water made it possible to use electrical methods for finding usable deposits. The use of different geophysical methods of exploration is recommended. Several examples of effective combination of methods are quoted.

114. *A Visit to Oilfields of Western Germany.*
Martin & A. Bertran de Lis, Mineria y Metalurgia, No. 127, pp. 9-21, 1951.
The geological features of the most important oilfields of northwestern Germany are briefly described. They now produce over 100,000 tons per month. In exploration, the seismic methods are principally used, but gravity, magnetic, and electrical methods are also employed. Success of prospecting has been, in some cases, outstanding. In Georgsdorf oilfield, of 12 wells which were located by geophysical methods 8 were found to be productive.

115. *Geophysical Research Institution of the University of Copenhagen.*
Nature, Vol. 169, No. 4298, p. 441, March 15, 1952.
In order to promote geophysical research at the University of Copenhagen, a private and independent institution has been created with Dr. Niels Arley as director. It will be known as the Geophysical Research Institution, University of Copenhagen. The Institution plans to continue on future deep-sea expeditions the work of measuring the geomagnetic field in the oceans as a function of position, depth, form and physico-geological nature of the bottom, and time (secular variation); to investigate the magnetism of bottom samples, rocks, etc., by means of the spinning magnetometer

presented to Dr. Arley by Prof. M. A. Tuve, of Washington; to organize a comprehensive and systematic geophysical survey of Greenland.

116. *Expansion of Geophysical Activity Unprecedented.*
Dr. E. A. Eckhardt, World Oil, Vol. 134, No. 5, pp. 90-91, 1952. Geophysics, Vol. XVII, No. 3, pp. 441-451, July, 1952.

During 1951 there was an unprecedented increase in geophysical activity. There were 791 seismic crews operating — an increase of 134 over 1950. Gravity crews numbered 123 — an increase of 13 over 1950.

In view of the difficulty of recruiting sufficient men with the proper training, the rise in activity is remarkable.

A graph and a number of charts are presented in this review of geophysical activity throughout the world.

117. *Geophysics plays more Important Part in Search for Subsurface Information.*
LeRoy Scharon, Mining Engineer, Vol. 4, No. 2, pp. 160-163, Februay, 1952.

Geophysics is being used much more in mining and engineering than ever before. It has served in finding ore deposits of numerous minerals and has assisted in the selection of sites for big engineering projets.

An annual review is given of geophysical activity in the various states of North America, Canada, Europe, Africa, Asia, Australasia and South America. A short report on the more important and recent geophysical research carried out is included.

118. *Geophysical Crews have Busiest Year.*
World Oil, Vol. 134, No. 3, p. 79, February 15, 1952.

In the U.S.A. at the end of 1951 there were 529 seismic, 73 gravity, 6 magnetometer, and 26 core-drill crews operating. These figures compare with the end of 1950 when there were 405 seismic, 50 gravity, 3 magnetometer and 22 core-drill crews. The total for 1951 of 634 crews compares with the total for 1950 of 480.

A table is presented detailing distribution of the crews in the various States for two year ends.

119. *Geophysical Exploration comes of Age.*
S. Hammer, Petroleum Engineer, Vol. 24, No. 4, pp. B-84-88, April, 1952. Geophysics, Vol. XVII, No. 3, pp. 435-440, July, 1952. Bull. Amer. Ass. Petrol. Geol., Vol. 36, No. 7, pp. 1318-1322, July, 1952.

This is the Presidential Address delivered at the joint Annual Convention of the A.A.P.G., S.E.P.M., and S.E.G., at Los Angeles on March 25, 1952.

The author reviews the growth of geophysical exploration, particularly in the U.S. but not ignoring foreign developments; he summarizes the position of geophysical exploration today; and he outlines future prospects.

Last year, official S.E.G. records show $ 325,000,000 were invested in world-wide geophysical explorations by the oil industry.

120. *Introduction to Geophysical Prospecting.*
M. B. Dobrin, Oil & Gas J., Vol. 50, No. 46, pp. 124-162, March 24, 1952.

The article presents excerpts from the book by M. B. Dobrin, which describes the fundamental principles and operations of the standard methods of geophysical prospecting.

121. *Gulf Secrets Sought.*
Dahl. M. Duff, Oil & Gas J., Vol. 50, No. 50, pp. 96-97, April, 1952.

Scientists from the Lamont Geological Observatory are carrying out a programme in the Gulf of Mexico to determine the thickness and character of the sedimentary layer and the nature of the basement rocks.

122. *Geophysical Activity in Western Canada.*

H. M. Houghton, World Petroleum, Vol. 23, No. 5, pp. 90-93, May, 1952.

Bar graphs are presented which illustrate the growth of geophysical activity in each province during the period 1946-1951. The cost of this work is given in detail. Most of the operations have to be carried out during the winter when the muskeg is frozen and able to support equipment. A diagram shows how the ice of a frozen river is reinforced to carry heavy vehicles.

123. *Structural Correlation of Micromagnetic and Reflection Surveys.*

W. P. Jenny, World Oil, Vol. 134, No. 4, pp. 67-72, March, 1952.

Practical co-ordination and structural correlation of micromagnetic and reflection surveys in the search for oil are discussed. Because both methods work within the sedimentary section, micromagnetics at shallow depths and reflections at greater depths, they seem destined to complement each other. On the strength of four examples, an attempt is here made to show how a correlation of the two methods could introduce new aspects into the interpretation of prospects.

124. *Safety and Geophysical Exploration.*

B. W. Sorge, Geophysics, Vol. 17, No. 2, pp. 236-243, April, 1952.

The safety and accident prevention record of geophysical operations has substantially improved during the last decade. A well planned safety and accident-prevention programme which has the full support of all parts of an organization will produce results. Many advantages can be obtained by improving co-operation in safety matters among operators of geophysical crews.

125. *Geophysical Exploration of Southwest Hungary.*

R. Vajk, Geophysics, Vol. 17, No. 2, pp. 278-310, April, 1952.

Geophysical exploration of an eight million acre oil concession covering southwest Hungary is discussed. During ten years of exploring (1933-1943), about 20,000 torsion balance, 12,000 gravity meter, and 15,000 magnetometer stations were made, and reflection seismograms were recorded at about 2,500 shot points. As a result of this exploration, four oil pools and a gas pool were discovered and a number of geological structures and major faults were located. Gravity, magnetic and seismic maps showing most of the geophysical data are submitted. Interpretations of the geophysical results, geological data from subsequent drilling, and a schematic tectonic map of south-west Hungary based on the geophysical surveys are also presented.

126. *Prospecting by Geophysical Methods.*

D. T. Germain-Jones, Nature, Vol. 170, No. 4319, pp. 230-231, August 9, 1952.

At the 2nd meeting of the E.A.E.G., held at Mansion House, London, May 22-23, several papers were read.

Mr. H. Linnser (Germany) described the mechanisms of a seismic explosion showing which phase of it propagates seismic energy.

Mr. T. Krey (Germany) showed the importance of diffraction in the detection and mapping of faults.

Mr. J. Goguel (France) described a special slide-rule which he has developed for the rapid determination of a series of refracting beds, with small dip, from the observed time-curve.

Prof. J. M. Bruckshaw (Great Britain) and P. C. Mahanta (Great Britain) described laboratory investigations on the variation of the elastic constants of rocks with frequency.

Dr. O. Rosenbach (Germany) in a paper on securing maximum information from gravimeter observations, described a development of the second derivative method of interpretation, originally published by T. A. Elkins.

Dr. V. Baranov (France) also talked about gravity interpretation. He presented an interesting analytical method of determining the regional anomaly.

Prof. K. Jung (Germany) described two geometrical constructions for determining the approximate positions of buried bodies of simple form from their gravity or magnetic anomalies.

Mr. M. Mainguy and Mr. A. Grepin (France) described some practical examples of interpretation of telluric maps obtained in France.

Mr. G. Kunetz (France) dealt with the elimination from telluric observations of stray earth currents from man-made installations.

127. *Exploration Problems of the Williston Basin.*

K. E. Burg, Geophysics, Vol. XVII, No. 3, pp. 465-480, July, 1952.

Discovery of oils in North Dakota, in the vicinity of the Nesson Anticline, near the centre of the Williston Basin, initiated a very active exploration programme covering the entire basin. Interest in the area has continued because many of the wells drilled in other portions of the basin have resulted in discovery of oil in commercial quantities.

Because of the wide regional extent of the Williston Basin and presence of a rather complete Mesozoic and Palaeozoic section, many exploration problems are encountered. The role of the seismograph in the solution of these problems is discussed.

128. *Five Years of Geophysics in Western Canada.*

H. M. Houghton, Oil in Canada, Vol. 4, No. 29, pp. 19-24, 1952.

A statistical study of operational problems peculiar to the bush country in northwestern Alberta.

SEISMIC — GENERAL

129. *Pemex Discoveries owed largely to Seismic Surveys.*

Oil Forum, Vol. 6, No. 3, p. 97, March, 1952.

Reflection seismograph methods were responsible for the discovery of the Jose Colomo field—proven reserves of 250,000,000 bbl.—and the smaller Trevino field. A combination of seismic reflection and refraction methods were used to discover the Rabon Grande field which has estimated reserves of 50,000,000 bbl.

130. *Foreign Hazards Speed Trend to Contractor.*

H. C. Hoover, Oil Forum, Vol. 6, No. 3, pp. 73-76, March, 1952.

To undertake complete modern seismic services on a world-wide basis, a company must have a multi-million dollar investment and a staff of personnel willing and able to meet such extreme and dangerous situations as: the sudden windstorm of the Arabian desert; the tropical flash floods of western Venezuela; the tidal encroachment of southern Chile; the race massacres of India; and the political upheavals of various foreign oil-producing countries. In order to accomplish his assignments, the party chief of a foreign seismic survey may be called on to a degree unknown in domestic operations to make decisions on which rests the preservation or destruction of this equipment, and in some cases involving the very lives of his men.

131. *Studies in Non-structural Petroleum Prospecting (the Comparative Resolution of Pertinent Gulf Coast Refraction Anomalies).*

E. E. Rosaire, Geophysics, Vol. 17, No. 2, pp. 244-277, April, 1952.

For the case of low-relief structure associated with petroleum accumulation, the non-structural working hypothesis postulates the observation of refraction fan anomalies with characteristics which are unique when compared with those of the refraction fan anomalies postulated by the geophysical structural working hypothesis generally accepted for the resolution of refraction fan anomalies.

These unique characteristics are observable magnitudes on depth of survey too shallow to intercept the underlying structure, double peaked maximum configuration, off-structural orientation of maximum leads, and change in type of configuration as the survey depth increases to structural interception.

Case treatments are shown where such structurally forbidden refraction fan anomalies were observed across low-relief structure associated with petroleum accumulation, subsurface conditions which were revealed by subsequent development. These case treatments are substantiating evidence for the non-structural working hypothesis in Gulf Coast refraction prospecting.

132. *Seismic Observations in Weststeiermark.* (In German).

H. Lackenschweiger, Berg und Hüttenmännische Monatshefte, Vol. 97, No. 6, pp. 111-113, 1952.

The aim of this refraction survey (mainly fan shooting) was to discover small size coal basins hidden below a tertiary blanket. During 7 months, 325 shots were observed with the aid of a 4-trace recorder, and 2700 kg. of explosive were used. The resulting velocities were: Tertiary 2100-2800 m/sec., Cretaceous 3200-3800 m/sec., Primary 4200-5000 m/sec., Basement 5500 m/sec. Two of the discovered basins have been checked by drilling. Seismic depth indications proved to be correct but no coal seams were present. The cost of seismic and topographic surveying was 120 km^2: 430.000 Austrian Shillings.

133. *Offshore Seismic Exploration in the Ube Coal Field.* (In Japanese with English Summary).

K. Iida & S. Kurihara, Geol. Surv. Japan, Rept. 146, 1952.

An account of the exploration of the offshore extension of the Ube coal field with the seismic refraction method is given. Best progress was obtained (shooting 3-6 spreads/day) by dragging the 6 detectors on wooden sleds along the flat sea bottom. A total of more than 30 profiles, between 1 and 10 km long, were shot. The resulting velocities were: Quarternary sediments 1300-1800 m/sec., Tertiary 2200-3200, Coal-bearing rocks 3800-6500 m/sec. The depth of the latter varies from 150 m to over 300 m and is found to be intersected by a complicated pattern of faults and folds. The survey is tied into existing boreholes and the results are checked by a few additional holes.

SEISMIC — INSTRUMENTAL

134. *A new Instrument for Seismic Exploration at very Shirt Ranges.*

D. I. Gough, Geophysics, Vol. 17, No. 2, April, 1952.

An instrument is described for use in seismic investigation of subsurface structure to a maximum depth of about 100 feet. A hammer is used as a source of seismic energy. A cathode-ray tube replaces the usual galvanometers as display device, and seismic arrivals are timed electronically by a modified radar technique. Applications will lie mainly in the field of civil engineering. Field tests made at a dam site are compared with direct borehole tests of the subsurface structure.

135. *Patents.* Abstracts in Geophysics, Vol. 17, No. 2, p. 396, April, 1952.

U.S.2,576,775.	27 Nov., 1951.	A three-component earthquake seismometer.
U.S.2,577,472.	4 Dec., 1951.	Circuit for multi-channel recording galvanometers.
U.S.2,578,133.	11 Dec., 1951.	A system of seismic recording.
U.S.2,578,877.	18 Dec., 1951.	Seismograph blaster time breaker circuit.
U.S.2,570,707.	9 Oct., 1951.	A towing line for marine seismic work.
U.S.2,572,255.	23 Oct., 1951.	A towing line for marine seismic work.

136. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 627, July, 1952.

U.S.2,581,063.	1 Jan., 1952.	Type of Geophone.
U.S.2,581,091.	1 Jan., 1952.	A continuous-line geophone.
U.S.2,581,994.	8 Jan., 1952.	A cable provided with polarized outlets for seismic prospecting.
U.S.2,582,714.	15 Jan., 1952.	A.V.C. time response switching.
U.S.2,582,769.	15 Jan., 1952.	A moving coil seismometer.
U.S.2,582,793.	15 Jan., 1952.	Seismograph recording apparatus.
U.S.2,584,386.	5 Feb., 1952.	A low-frequency band-pass filter.
U.S.2,585,854.	12 Feb., 1952.	An A.V.C. circuit for an amplifier.
U.S.2,588,291.	4 March, 1952.	A distortionless seismic wave filter.
U.S.2,590,822.	25 March, 1952.	A time-actuated automatic filter.

SEISMIC — FIELD TECHNIQUE

137. *Evaluation of Interlocking Recording in their Application to Seismic Methods of Prospecting.* (In German).

T. Krey, Erdöl u. Kohle, Jahrg. 4, Heft 7, pp. 385-387, 1951.

Two seismic recording arrangements are compared. In the first method several seismometers, used in series or parallel, feed a single recording trace; this is called 'multiple detection'. In the other method, each seismometer feeds two or more recording traces; this is called 'composite' or 'interlocking recording' with overlapping seismometer. It is shown that in composite recording 50% more seismometers are required in order to obtain the same reliability. The moments of respective arrival of reflected waves to seismometers are assumed to coincide. Similarly it can be shown that in composite recording of reflected waves with small phase differences interpretation can become very difficult. This is not so when the phase differences at individual seismometers are equal to $\pi/2$ or more. However, the great usefulness of multiple recording in practical work is emphasized.

138. *The Development of a new Method of Seismic Velocity Determination.*

F. P. Kokesh, Geophysics, Vol. 17, No. 3, pp. 560-574, July, 1952.

Considerable interest has recently been aroused in a new method for measuring seismic velocities wherein the explosive charge is placed in the hole and the seismic energy is picked up by detectors on the surface. Experiments carried on during the last year indicate that the new method is quite workable. This paper attempts to outline the basic problem of velocities and their measurement and describes the preliminary development on the new method of velocity measurement. It has been demonstrated that by using standard perforator guns loaded with bakelite bullets, velocity surveys down to 5000 feet can be obtained, and probably down to 10,000 feet by exploding prima cord in a well.

139. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 627, July, 1952.

U.S.2,580,636.	1 Jan., 1952.	Method of arraying seismis reflection geophones.

U.S.2,586,731.	19 Feb., 1952.	Method of generating seismic waves on the surface of the ground.
U.S.2,590,530.	25 March, 1952.	Cable and geophone assembly for use over water-covered areas.
U.S.2,590,531.	25 March, 1952.	Cable and geophone assembly for use over water-covered areas.

140. *Patents.* Abstracts in Geophysics, Vol. 17, No. 4, p. 953, October, 1952.

U.S.2,596,463.	13 May, 1952.	Seicmis refraction method.
U.S.2,599,245.	3 June, 1952.	Marine seismic shooting method.
U.S.2,601,522.	24 June, 1952.	Seismic shooting method.

SEISMIC — INTERPRETATION

141. *The Precision of Travel-Time Curves in the Seismic Method of Geophysical Prospecting.*

A. A. Fitch, E. H. Lloyd, Proc. Third World Petrol. Cong., Section 1, pp. 497-513, 1951.

Precision in measurements of time, distance, and elevation at which seismic impulses are recorded and its value in structural interpretation of data are considered. Straight line paths are assumed and an expression is derived for the deviation of the angle of dip. The expression has two terms; the first accounts for errors of observation—the second for errors in velocity of rocks above the refracting or reflecting layer. Examples are given, showing the former to be the larger error. Accuracy is best improved by increasing the number of detectors and decreasing the spacing.

142. *The Effect of Errors in Measurements on the Determination of the Dip and Depth of a Reflecting Boundary.* (In German).

L. Krousky, Erdöl u. Kohle, Jahrg. 5, Heft 4, p. 210, 1952.

An analysis of the influence of errors in measurements of travel time, distances between geophones, and other parameters. A special case is when the position of a salt dome with steep flanks is to be determined. The total error is computed, using Taylor's formula, from the errors made in evaluating individual parameters entering into formulae.

143. *Reflections in the Interior of Salt Domes and their Importance in Petroleum Exploration.* (In French).

T. Krey & B. Helwich, Proc. Third World Petrol. Cong., Section 1, pp. 583-589, 1951.

On a number of German salt dome surveys, the reflected seismic waves have been found to pass through the salt. They may have been reflected from the interior of the lateral or overhanging face, or a contact between two Permian horizons, both containing salt layers, which constitute the dome. The interpretation of this type of reflection is discussed.

144. *Seismograph Interpretation as related to Changes in Sedimentary Section.*

J. Daly & C. N. Page, Petroleum Engineer, Vol. 24, No. 9, pp. B. 36-50, July 15, 1952.

Now that the seismograph is being used successfully on reefs and other stratigraphic problems, it is becoming more than ever important to have better velocity control and closer correlation between the geologic and seismic information. Velocity changes can obscure or distort seismograph observations that would otherwise reveal desirable geological factors. Also, velocities can be a clue to lithology. Hence the greatest possible number of well velocity surveys is necessary.

145. *Generation and Propagation of Strain Waves in Rock.*
L. Obert & W. I. Duvall, U.S. Bureau Mines Dept. Inv. 4683, 19 p., 1950.

The 'near shot' generation and propagation of strain waves has been studied for shot sizes from 1-100 lbs. First, strain gauges and recording equipment were developed which could be employed in solid media (rock). Field studies were made in a number of rock types, and an empirical relationship contains two constants which can be related to the rock type, and these parameters can be compared through the evaluation of these constants.

The strain pulse resulting from the application of a steep function pressure pulse to a spherical cavity in a solid medium has been calculated and compared with recorded strain pulses. Also, the resonance of a spherical cavity in a solid medium driven by a sinusoidal source has been calculated and the results compared with field data.

146. *Rayleigh Waves propagated along the Plane Surface of Horizontally Isotropic and Vertically Aelotropic Elastic Body.*
Y. Sato, Tokyo Univ. Earthquake Research Inst. Bull., Vol. 28, Pts. 1-2, pp. 23-29, 1950.

Using the expressions derived by S. Homma, the mathematical existence of one and only one kind of Rayleigh wave in horizontally isotropic but vertically aelotropic semi-infinite elastic medium is demonstrated.

147. *Vibration Measuring Equipment with Electronically Variable Constants.*
F. Gassmann & M. Weber, Mitt. Inst. Geophys. E.T.H. Zürich, No. 16, p. 4, June, 1951.

This is a mathematical paper in which the constants of the equation for the displacement of the moving part of a mechanical seismograph are considered and transformed into the electrical characteristics of electronic amplifiers and recording equipment fed by signals from an electrical pick-up. No details are given of electrical circuits.

148. *Mathematical Study of the Propagation of Waves upon Stratified Medium.*
Y. Sato, Tokyo Univ. Earthquake Research Inst. Bull., Vol. 29, Pt. 1, pp. 21-38, 1951.

Verification of a method for effecting approximate calculations in practical cases.

149. *A Note on Air-coupled Surface Waves.*
N. A. Haskell, Bull. Seis. Soc. Amer., Vol. 41, No. 4, pp. 295-300, 1951.

Frequency-dependent coupling between the atmosphere and a denser underlying medium occurs whenever the properties of the latter permit propagation of vertical surface displacements with a phase velocity close to that of sound in air. The air-ice sheet-water coupling is an example of this phenomenon when the phase velocity of surface waves in the underlying medium increases with increasing frequency. This accounts for part of the ground roll in seismic records when phase velocity decreases with increasing frequency. The latter may also help to explain microseisms.

150. *Multiple Reflection on the Edwards Plateau.*
T. C. Poulter & L. V. Lombardi, Geophysics, Vol. 17, pp. 107-115, January, 1952.

Seismic records obtained at the same point with hole and surface charges are compared. Evidence is presented that multiple reflections from within the Edwards limestone are sufficiently prominent on the hole shot records to mask and obscure primary reflections. It is postulated that the large number of these multiples is attributable to the great amount of high frequency energy generated in the competent Edwards limestone by a hole shot.

The relative lack of multiple reflections on the Poulter Method records is believed to be due largely to the fact that essentially all of the energy entering the ground is of low frequency in the part of the spectrum available for deep reflections. This nullifies the apparent high frequency selectivity effect of the Edwards limestone.

151. *Rayleigh Wave coupling to Atmospheric Compression Waves.*

W. S. Jardetzky, & F. Press, Bull. Seism. Soc. Amer., Vol. 42, No. 2, pp. 135-144, 1952.

The theory of dispersive Rayleigh waves coupled to atmospheric compression waves is derived for the case of a solid surface layer. Numerical computation of phase and group velocity curves indicates that an additional branch may be introduced to the dispersion curves as a result of air coupling. This branch corresponds to a train of approximately constant frequency waves beginning with the arrival of the air wave and continuing to a time which depends on the distance and the classic constants of the layers.

152. *Control of Variables in the Observation of Seismic Echos.*

E. J. Handley, World Petroleum, Vol. 23, No. 3, pp. 66-69, 1952.

In seismic surveying, control of the variables in the recording set-up allows control to be exercised over the particular wave notions recorded. The factors which may be controlled depend on size and type of explosion, instrument set-up, use of electric mixing, and automatic volume control.

GRAVITY — GENERAL

153. *Principal Characteristics and Results of the Gravimetric Surveys made in Italy for Oil- and Gas Exploration.*

L. Solaini, Proc. Third World Petrol. Cong., Section 1, pp. 240-254, 1951.

In recent surveys of northern Italy, 3,500 stations were occupied in an area of 7,000 sq. km. Earlier surveys, in the Po valley and other areas, have covered 74,000 sq. km in less detail. The earlier surveys indicated major structural features which are due either uplift of Cretaceous or Miocene formations, or to the presence of igneous rocks. The small gravity anomalies of individual sedimentary structures have to be detected from the large and complex regional anomalies. By choosing station densities commensurate with the regional anomalies, local residuals of 0.2 mgal may be read. Regionals were eliminated by a graphic method and good agreement was found between residuals and sedimentary structures. Several examples are discussed.

154. *Gravimeter and Geological Structures.* (In French).

N. Oulianoff, Laboratoires de Géologie, Minéralogie, Géophysique et Musée Géologique de l'Université de Lausanne, Bull. 98, 1951.

A short description of the Worden gravimeter, its use, and the corrections to measurements. Geological problems which can be tackled by means of this instrument in Switzerland are reviewed.

155. *Isogam Maps of Caribbean Sea and Surroundings and of S. E. Asia.*

J. W. de Bruyn, Proc. Third World Petrol. Cong., Section 1, pp. 598-612, 1951.

Two maps, based on published pendulum observations and gravity surveys made by Royal Dutch Shell and affiliated companies, are presented on a scale 1 : 10,000,000 with contour intervals of 25 mgal. One map is of the Caribbean Sea and surrounding parts of North, Central, and South America; the other is of southeast Asia, including the East Indian (Malay) Archipelago, the Philippines, and New Guinea. The Caribbean map is based on Hayford-Bowie isostatic anomalies ($T = 113.7$ km) and the southeast Asia map on Vening-Meinesz regional isostatic anomalies ($T = 25$ km, $R = 160$ km). Bathymetric charts of the two regions, on the same scale, are also presented.

156. *Gravimetric Map of Poland.* (In Polish).
T. Olczak, Poland Inst. Geol. Bul., No. 64, pp. 59, 1951.

A gravity map of Poland giving Bouguer anomalies reduced to sea level, with 5 mgal contour intervals, shows that anomalies range from —40 to +40 mgal. The map was constructed from data obtained by geophysicists of the Polish Geological Institute from 1933 to 1938. Warsaw (981.2412 gal.) was used as base station.

GRAVITY — INTERPRETATION

157. *Comparison of Gravitational and Magnetic Anomalies over Certain Structures in Southeastern Ontario.*
G. D. Garland, Trans. Can. Inst. Min. & Metall., Vol. 54, pp. 340-345, 1951.

The anomaly of the total magnetic field caused by a buried body is related to the sum of three second derivatives of the anomalous gravitational potential, which can be calculated from surface measurements of gravity. This relation contains as a multiplication factor: anomalous magnetization over anomalous density. Thus by comparing magnetic and gravity anomalies in the same area, it can be decided whether these effects are due to the same body with uniform susceptibility and density. If so, a characteristic factor can be obtained, irrespective of size and depth of the body, serving as an aid to the identification of the composition of the body.

To illustrate this procedure, an airborne magnetic map and a residual gravity map of the Crow Lake intrusion are presented. They show the intrusion to be composed of two different types of rock. Other examples are discussed.

158. *Interpretation of Gravity Anomalies.*
Nature, Vol. 169, No. 4311, pp. 989-990, June 14, 1952.

A geophysical discussion on the interpretation of gravity anomalies, arranged jointly by the Roy. Astronom. Soc. and the Geol. Soc. was held on February 22, 1952.

B. C. Browne showed that 'g' remains practically the same over large land masses as over oceans. It was concluded that oceans and continents are compensated by different crusts and that mountain ranges, basins, etc. are compensated by variations in crust thickness.

P. Evans criticised the isostatic theory of Pratt, developed by Hayford and Bowie and applied to many parts of the world. He preferred Airy's theory. N. L. Falcon discussed the value of detailed gravity surveys in areas where geological conditions are only partly known. Dr. T. C. Richards thought that isostasy varied all over the world. D. R. Brown described a method whereby residual anomalies can be found by removing the regional effect.

Dr. G. M. Lees, summing up, said that in continental areas there were so many exceptions, where the isostatic principle did not apply, that he doubted its validity. He added that as an aid to geological exploration, gravity surveys have helped considerably where conditions have been favourable.

GRAVITY — THEORY & RESEARCH

159. *A Method of Correcting the National Gravimetric Network and its International Ties by Observation with a Gravimeter.* (In Spanish).
L. Lozano Calvo, Rev. Geofis., Vol. 10, No. 38, pp. 73-84, 1951.

Theoretically it is possible to make a gravity survey of the entire earth, using pendulum measurements, with only one base station. The accuracy of a base station determines the accuracy of its corresponding stations. Spain has a gravity network of 208 stations, with 5 pendulum base stations. By referring every measurement to a single ideal base station, which has been determined by the method of least squares, the precision of the network may be improved. Spain is used as an example in explaining the method, but gravitational ties between different national networks may be improved in the same way.

160. *Calibration of two Worden Gravimeters and the Tying of European Gravimetric Networks.* (In Italian).
C. Morelli, Ann. Geofis., Vol. 4, No. 4, pp. 493-524, 1951.

Two Worden gravimeters were tested to determine the possible precision attainable, the range of indications, and drift tendencies in the instruments, Relative gravity was determined at 18 observatories of the West German network. The precise value of 'g' at each observatory had recently been determined by pendulum methods. The range of measurements was about 1,500 mgal., the average error of measurements was less than 0.5 %, and the constants of the instruments varied linearly.

The following observatories were tied by repeated gravimeter measurements:

Uccle, g = 981.1320 ± 0.2
De bilt, g = 980.2688 ± 0.3
Padova, g = 980.6586 ± 0.4
Rome, g = 980.3616 ± 0.4
Paris, g = 980,9438 ± 0.3
Copenhagen, g = 981.5575 ± 0.4
Monaco, g = 980.7330 ± 0.4
Teddington, g = 981.1963 ± 0.2
Brunswick (Braunschweig), g = 981.2655 ± 0.1

Provisional correction, obtained from these measurements, to the present Potsdam system of — 13.9 ± 3.5 mgal. was found.

161. *Measurements of Gravity in Southern Africa.*
A. L. Hales & D. I. Gough, Published by Pretoria, Government Printer, 1951.

Absolute gravity measurements were made at 53 stations throughout southern Africa during 1948-49. Invar pendulums were used with a quartz frequency standard and checked periodically at the base stations, to enable 'g' to be measured with an accuracy of 0.001 cm/sec.^{2}. The free-air corrections agree with Jeffreys' in departing from the International Formula, but disagree with Tanni. Analysis confirms the presence of isostatic compensation in southern Africa, but data was insufficient for estimating its depth. The anomalies bore no significant relatonship to geologic structure.

162. *On the Distribution of Gravity Anomalies on the Island of Madagascar.* (In French).
L. Cattala, Acad. Sci. Paris Comptes rendus, Tome 234, No. 5, pp. 547-8, 1952.

The central massif of Madagascar has an anomaly of only 60-80 mgal./1,000 m of altitude. This fact supports Besaire's proposal that the massif is placed on a gabbroic substratum. Basaltic rocks, at or below the surface, or a thinning of sediments, may be responsible for positive anomalies along the coast. A gravity map of the area is shown.

163. *A new Gravity Formula for the Far East.*
H. Higasinaka, Acad. Japan Proc., Vol. 27, No. 9, pp. 577-581, 1951.

In a survey of underground structures around Japan and the Philippines, it is suggested that the gravity anomalies should be based upon the formula used for the neighbouring continent. A new formula, based on the Helmert gravity formula of 1901, permits the coefficients to take on small increments. These increments are determined by the method of least squares and by the use of gravity data for 287 stations in the Far East. The new formula differs slightly from the Helmert formula, but widely from the International formula. Since all the gravity anomalies in Japan have been based on the Helmert formula, they can be used for geologic interpretations.

164. *Earth Tides.*
Nature, Vol. 169, No. 4298, pp. 437-440, March 15, 1952.
(Brief account of Geophysical Discussion at the Royal Astronomical Society, London, on November 23, 1951).

A study of the distortion of the surface of the earth's land surface by the tidal potentials of the sun and moon yields evidence, more conclusive than that from seismology, that its central core is liquid. Moreover, the diurnal variation of gravity, which is a consequence of this distortion, is of great practical interest to prospecting geophysicists. Both theoretical and practical geophysicists were represented at a Geophysical Discussion on the subject, held in London on November 23, 1951. Accounts of work carried out were given by Dr. B. Baars of the Royal Dutch Shell Oil Co., Prof. H. Jeffreys, Dr. R. H. Corkan of the Liverpool Tidal Institute, and Prof. R. Tomaschek of the Anglo-Iranian Oil Co. Ltd.

165. *Three Dimensional Interpretation of Gravitational Anomalies.*
F. S. Grant, Geophysics, Vol. 17, No. 2, April, 1952.

A method is developed for determining the approximate size and shape of the three-dimensional mass distribution that is required to produce a given gravitational field. The first few reduced multi-pole moments of the distribution are calculated from the derivatives of the surface field, and the approximate structure is determined from the value of these moments and a knowledge of the density contrast between the body and its surroundings. A system of classification of problems by symmetry is introduced and its practical usage discussed. A relaxation method is described which may be used to adjust the initial solution systematically to give agreement over the whole field. A descriptive discussion is appended.

ELECTRICAL

166. *Studies on the Interpretation of Vertical Electrical Sounding.* (In Italian).
L. Alfano, Riv. Geofis. Appl., Vol. 12, No. 2, pp. 83-106, 1951.

The method for analysing the results of vertical electric sounding is applied to the problem of three strata. A formula is derived for the apparent resistivity of the lowest layer, approximations are introduced, and the resulting expression is similar to Hummel's formula. This, in certain cases, can be used in numerical computations and the necessary integral values can be determined graphically. An adaption of this method for treating the four-layer problem is suggested.

167. *Ten Years of Use of the Telluric Method.* (In French).
L. Migaux, Proc. Third World Petrol. Cong., Section 1, pp. 624-645, 1951.

Principles of the method are reviewed. Advantages and limitations are discussed, and some examples of surveys in Europe and Africa, with the results, are given.

168. *Quantitative Interpretation of the Data of Exploration by Telluric Currents.* (In French).
V. Baranov, Proc. Third World Petrol. Cong., Section 1, pp. 646-653, 1951.

A quantitative interpretation of telluric data consists of searching the current lines in the soil while knowing the density of the current measured at the surface. The cylindrical, or two-dimension problem can be resolved quite easily by a mathematical apparatus which seems no more complicated than that which is necessary in classical prospecting methods. The telluric method has, in the past, been purely empirical, but is now provided with a more secure mathematical basis.

169. *Contribution to the Electrical Prospecting in Shojingawa Sulphur Mine and Amenasugawa Sulphur Mine Hokkaido.* (In Japanese with English summary).
M. Murozumi, Bull. Geol. Surv. Japan, Vol. 2, No. 7, pp. 21-29, 1951.

Electrical prospecting was applied by means of S. P. and resistivity methods to both mines in order to know the dimensions of sulphur ore deposits and to discover new ore deposits. In the Shojingawa mine two remarkable S. P. anomalies and some high resistivity zones have been found at the western side of the ore deposit worked now, and some indications by which the necessity of the future prospecting will be suggested are found at the southern end of this deposit. In the case of the Amenasugawa mine, both S.P. anomalies and high resistivity zones have been found at the same place. These anomalies are distributed in the silicified zones. On the other hand, low resistivity areas which would appear in a clayey zone are found at the southern side of these high resistivity zones. Some suitable places are pointed out for core drilling in these mines as a result of the prospecting.

OTHER METHODS

170. *Improved Instruments stimulate use of Airborne Radioactivity Surveys.*
Hans Lundberg, Oil & Gas J., Vol. 50, No. 49, pp. 165-166. April 14. 1952.

A scintillation counter has been developed which has obtained positive results in Texas and Canada. The results are obtained in the form of continuous gamma-ray recordings along parallel flight lines, laid out at regular intervals according to predetermined pattern. The altitude of the aircraft may vary between 150 and 500 feet above the ground and its speed may be as fast as 150 to 180 m.p.h. The author gives details of plotting and interpretation of results.

171. *Surveying Radioactivity Distribution as an Indication of Oil & Gas.*
H. Lundberg, World Petroleum, Vol. 23, No. 5, pp. 104-105, May, 1952.

The same article as above, varied a little.

172. *Black Light Aids Oil Exploration.*
Petroleum Engineer, Vol. 24, No. 4, pp. B-103, April, 1952.

The fluorescence of petroleum under long-wave ultra-violet lamps in some cases permits direct prospecting. Even slight traces of oil will fluoresce. A particular fluorescence in top soil will indicate petroleum hundreds of feet below.

A long-wave ultra-violet unit has been manufactured that operates on 110 volts a.c. or d.c. and has space for two 45 volt 'B' batteries. This gives the explorer a complete 3-way lamp and carrying case, including the daylight viewing compartment.

173. *Note on the Radio-Transmission Demonstration at Grand Saline, Texas.*
W. M. Barret, Geophysics, Vol. XVII, No. 3, pp. 544-549, July, 1952.

Some three years ago a group of scientists witnessed a demonstration involving the propagation of strong radio signals from a surface transmitter to a receiver located 700 feet below the surface in a salt mine at Grand Saline, Texas.

Since that time two misconceptions have arisen concerning the demonstration, namely: (1) that the signals were not transmitted through the earth, but instead, reached the receiver by travelling through the mine shaft, and (2) that considerable power was required at the transmitter, which implied high earth attenuation of the signals.

This paper presents evidence that denies these beliefs.

SOME PRACTICAL EXAMPLES OF INTERPRETATION OF TELLURIC METHODS IN LANGUEDOC (SOUTH-EASTERN FRANCE) *

BY

M. MAINGUY ** AND A. GREPIN **

ABSTRACT

In the region covered by the paper, electrical methods have been applied in four different zones:

a) Ales-Maruejols Basin (resistive lower Oligocene blanketed by conductive Upper Oligocene);

b) Ledignan and Vaunage-Lunel anticlines (faulted structures in the marly and limy Cretaceous, with different resistivities;

c) Camargue (thick series of conductive sediments);

d) Beziers Basin (highly complicated structures in the Mesozoic, widely blanketed by conductive Miocene).

It may be assumed that electrical methods can yield valuable information enabling one to define the rugged subsurface topography of resistive strata burried under a reasonably thick cover of conductive sediments especially when a part of the lower formation outcrops even if the part exposed be small. Faults may be delineated and much more information is obtainable than can be expected from gravity meter survey at a price not very much higher.

Electrical methods of prospecting, and especially the telluric method, have been widely used in France and the French Union. Numerous publications, the last of which is a paper delivered by Mr. Migaux to the IIIrd W.P.C. [1], have described the principles of the method and some attempts of mathematical interpretation (Mr. Baranov [2]). The purpose of this paper is to give some examples of empirical interpretation of such documents, considered by a geologist from a purely naturalistic standpoint.

In the region covered by this paper (concession of the S.N.P.L.M. in South-eastern France) telluric methods have been in use in four different zones where the interesting horizons, generally resistive, are more or less hidden by conductive strata. A first comparison with the gravimetric maps leads to the following observations:

in some cases, a practically perfect check of one method by the other is

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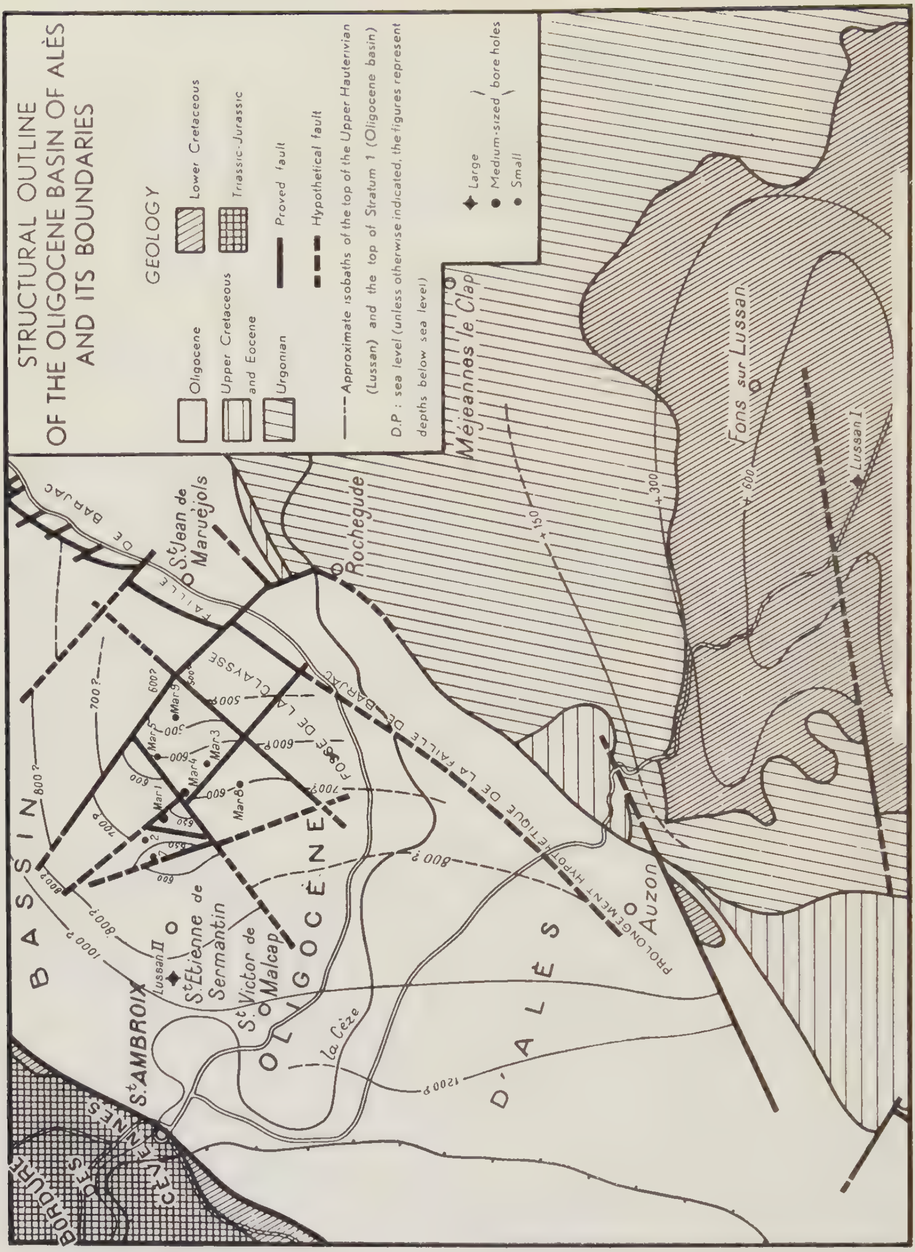
* Presented at the London Meeting of the European Association of Exploration Geophysicists, May 22/23, 1952.

** Société Nationale des Pétroles du Languedoc Méditerranéen.


STRUCTURAL OUTLINE OF THE OLIGOCENE BASIN OF ALÈS AND ITS BOUNDARIES
GEOLOGY
Oligocene
Upper Cretaceous and Eocene
Urgonian
Lower Cretaceous
Triassic-Jurassic
Proved fault
Hypothetical fault
Approximate isobaths of the top of the Upper Hauterivian (Lussan) and the top of Stratum 1 (Oligocene basin)
D.P.: sea level (unless otherwise indicated, the figures represent depths below sea level)
Large
Medium-sized
Small
bore holes
BASSIN OLIGOCÈNE D'ALÈS
FAILLE DE BARJAC
FOSSE DE LA CLAYSSE
PROLONGEMENT HYPOTHÉTIQUE DE LA FAILLE DE BARJAC
BORDURE DES CÉVENNES
St. AMBROIX
St. Etienne de Sermantin
St. Victor de Malcap
St. Jean de Maruéjols
Rochegude
Méjeannes le Clap
Fons sur Lussan
Auzon
La Cèze
Lussan II
Lussan 1
Mar 1
Mar 3
Mar 4
Mar 5
Mar 8
Mar 9
+150
+300
+600
500
600
700?
800?
1000?
1200?

obtained. This is very frequently the case in Languedoc where the resistive layers generally comprise dense limestone, and the gravimetric highs are also telluric highs;

in the other cases, significant discrepancies occur, as for instance when conductive layers are dense (or resistive layers, light) or when a uniformly dense series is composed of alternatively resistive and conductive horizons.

In the second case, it is obvious that telluric maps may give more (or at least, different and complementary) information than gravimetric ones. In the first case, the usefulness of running both surveys is less clear, and we must rely, for a judgement, on empirical comparison. Anyway, the telluric maps keep the advantages that have been underlined in Mr. Migaux's paper, i.e.:

a) that it is not subject to the effect of very deep horizons, especially irregularities in the cristalline basement, so that no empirical "regional anomaly" has to be drawn;

b) that a scale of resistivities is easier to obtain before drilling by the mean of electrical soundings than a scale of densities is.

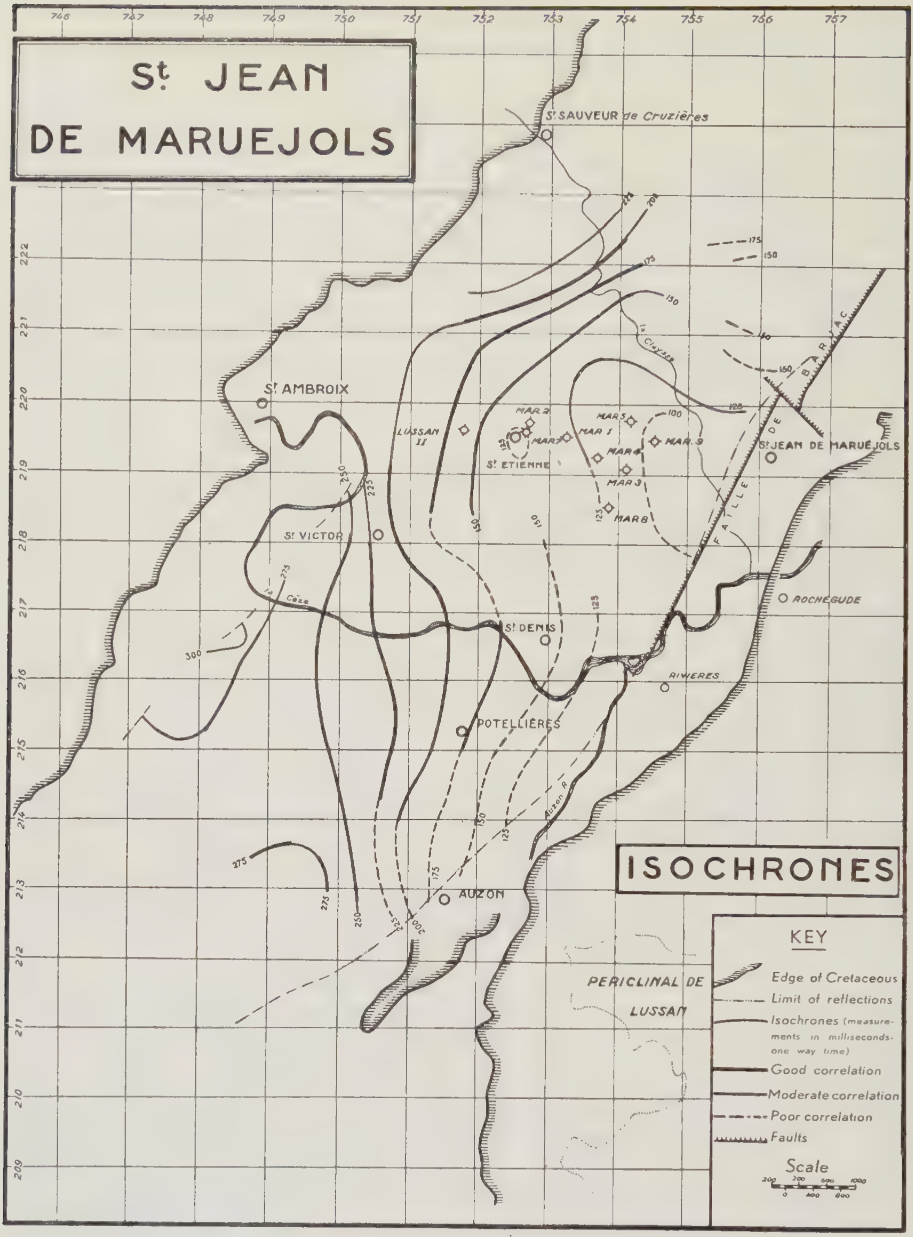
In many cases the interpretation of telluric surveys, supplemented by electrical soundings, appears easier at reasonable depths than the interpretation of a gravimetric map.

Particular mention must be made of the Beziers survey because it provides a good example of the possibility of eliminating the effect of industrial parasite currents (electric railway station). After such elimination, the map, which was formerly uninterpretable, checked pretty well with the detailed gravity survey, and agreed with the general idea of the tectonic trend of the basin. It is not possible to give any more detailed interpretation of that map, the region being so complicated that no clear picture could have been drawn from any of the prospecting methods applied up to now.

The most significant example, among the four cited areas, is that of Alés-Maruéjols, because it has been checked by wells, and has lead to the discovery of oil.

The Alés-Maruéjols basin appears on a geological map as an asymmetrical syncline, the NW flank of which is so steep and consequently so narrow that the entire basin can be regarded as a regular homocline dipping NW. Nearly the whole basin is covered by Upper Oligocene, except on the eastern flank where a narrow outcrop of lower Oligocene occurs extending NE-SW between two faults and comprising asphaltic limestones. A slight unconformity is known to exist in the region between Lower and Upper Oligocene, but was not supposed at first to be important enough to give the Lower Oligocene a completely different tectonic pattern from that of the Upper Oligocene, known from the surface.

The gravimetric map gives some vague indications of a high in the region but the difficulty is that of isolating the different effects the summation of which gives rise to the total gravimetric effect e.g.: plunging of the Cevennes


St JEAN
DE MARUEJOLS
ISOCHRONES
St SAUVEUR de Cruzières
St AMBROIX
St VICTOR
LUSSAN II
MAR 2
MAR 7
MAR 5
MAR 1
MAR 4
MAR 3
MAR 8
MAR 9
St ETIENNE
St JEAN DE MARUEJOLS
FAILLE DE BARJAC
ROCHEGUDE
St DENIS
RIVIERES
POTELLIÈRES
AUZON
Auzon R.
la Cèze
la Claysse
PERICLINAL DE LUSSAN
KEY
Edge of Cretaceous
Limit of reflections
Isochrones (measurements in milliseconds-one way time)
Good correlation
Moderate correlation
Poor correlation
Faults
Scale
200 200 600 1000
0 400 800
746 747 748 749 750 751 752 753 754 755 756 757
222 221 220 219 218 217 216 215 214 213 212 211 210 209
300
275
250
225
200
175
150
125
100

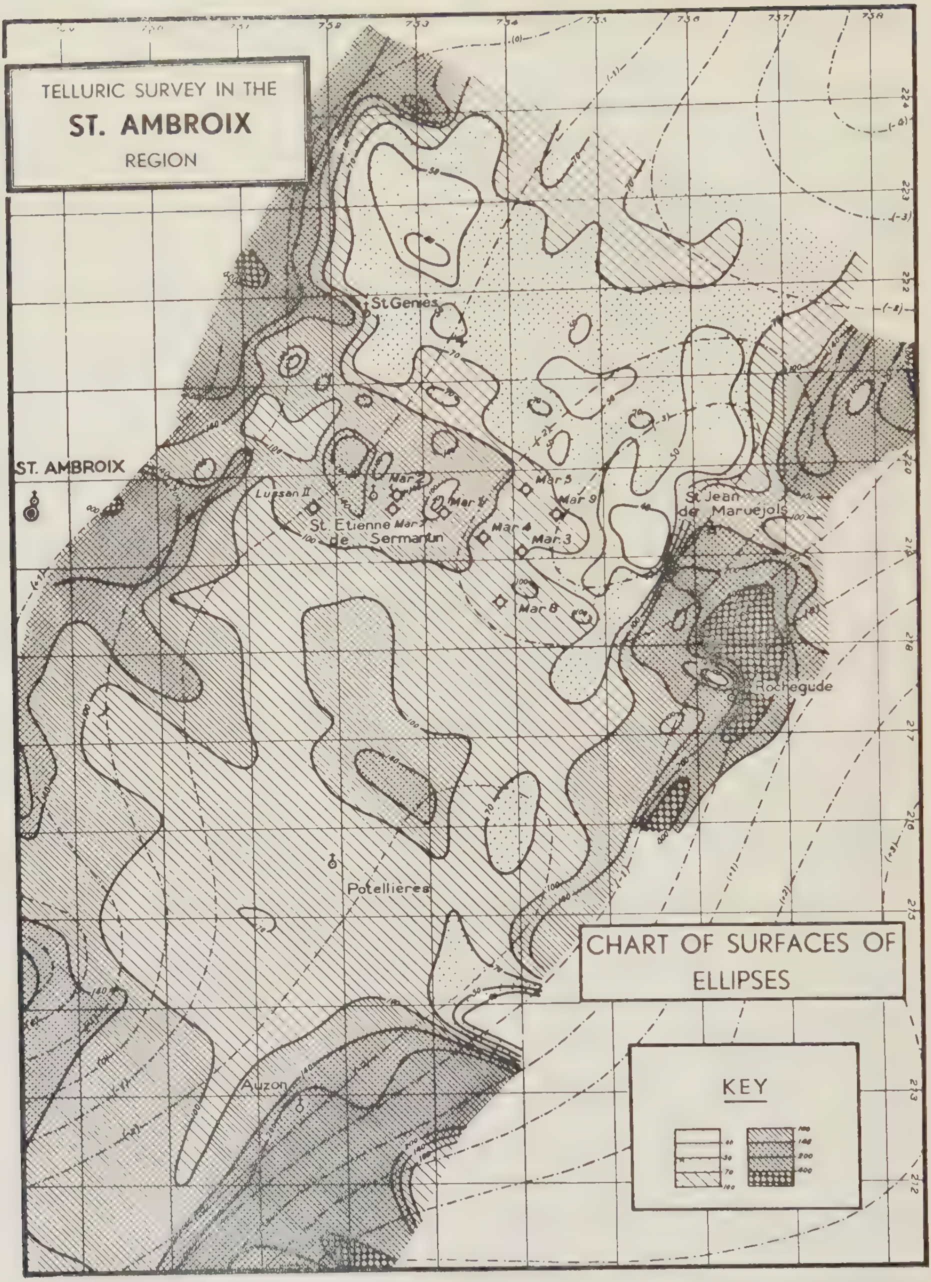
basement, lateral changes within the Cevennes basement, thickening of the Mesozoic, faulting and formation of the Tertiary basin.

The telluric map is much clearer, but, locating the high to the west, it looked in contradiction with surface evidence. After lengthy arguments, geologists being reluctant to accept such interpretation, the well was eventually located slightly on the flank of the telluric high, and struck oil in Lower Oligocene at a depth of 820 mètres. A seismic survey was then carried out, covering the basin, which gave the picture of a plunging nose, the axis of which was trending SE-NW, parallel to that of the telluric high, but which, according to surface evidence, plunged to the north-west, the eastern part of the basin being faulted. These results gave strength to the opinion that the telluric survey was a failure; the basin being apparently homoclinal, the closure could be regarded as stratigraphic, or provided by an asphalt plug, so that, if the whole homocline was not impregnated, the discovery of Maruéjols no. I might be regarded as the gift of hazard. The subsequent wells were located to the east of the basin, i.e. up dip according to the surface evidence and reflection seismic. They are actually down dip; the faults to the east delineate a trough filled with Upper Oligocene. Such a trough, masked by the unconformity of Upper upon Lower Oligocene, appears clearly on the telluric map, the difference in resistivity between both formations being much larger than their difference in density. Eventually, the combination of telluric data—the significant trends of high gradient zone giving the faults, frequently checked by mining work—and seismic data giving dip and strike, allow the drawing of a contour map. The wells checked the main conclusions (see Plate) of the telluric survey which, moreover, gives valuable information on Lower Oligocene and about the unconformity between Upper and Lower Oligocene.

The discovery was eventually non commercial because of the high sulphur content of the oil: the technical success remains and must be attributed to telluric survey, in opposition with all other data.

The results of the Lunel area, which covers a very composite region from a geological point of view, have been checked by wells partially. Their interpretation will be briefly described, because they show another way of using telluric survey. Two different regions are clearly apparent: one conductive, to the south-east, the other resistive in the north-west, separated by a zone of relatively steep gradient. The boundary between the two is well known to be a big fault, the existence of which, suspected by geologists, has been demonstrated by gravimetric survey, and detailed by telluric survey. The conductive basin was interpreted as Lower Oligocene at a depth of 1,000 to 1,100 metres: top Oligocene was at 986 m. The most conductive part of the basin is hardly to interpret, due partly to the thickness of the conductive cover and partly to large resistivity changes in surface (from resistive conglomerate to conductive salty sands).

In the northwestern part of the map, only a small part of the region has outcropping Jurassic or Cretaceous, the remnant being covered by Miocene and


TELLURIC SURVEY IN THE
ST. AMBROIX
REGION
St Genies
ST. AMBROIX
Lussan II
Mar 2
Mar 1
St. Etienne
de Sermantin
Mar 7
Mar 5
Mar 9
Mar 4
Mar 3
Mar 8
St Jean
de Maruejols
Rochegude
Potellieres
Auzon
CHART OF SURFACES OF
ELLIPSES
KEY

Pliocene, the thickness of which is not known. The clue to the interpretation of the map is very simple: Jurassic and Cretaceous being composed of alternatively resistive limestone and conductive marls, the structure is underlined by alternatively conductive and resistive zones, which can be followed under the conductive mask. Moreover, some small electrical indications are coming more to the front on account of their coincidence with slight surface indications, which, in their turn gain importance from their presence on a significant electrical trend. The usefulness of the telluric method in this case is in:

defining the prolongation of electrically differentiated outcrops under conductive mask;

explaining slight surface indications;

defining faults.

A reconnaissance survey having roughly marked the main line of the tectonics, one may wonder whether gravity survey could have given such detail if it had been run with the same density of measurements as the telluric. It is hard to believe, because the throw of the faults looks too small to affect gravity, while the contact of highly differentiated strata is so marked from the electrical point of view.

In the above mentioned two cases, telluric has given coherent and valuable results, generally more detailed than gravity, and in one case more so than seismic, the interpretation of which it has helped. In the basin of Alés, telluric led to the location of a discovery well. On the other hand, in the conductive Tertiary basin south of Lunel (a part of the basin of "Camargue occidentale") the results seem to be related to very shallow layers and are of no practical use as regards the interesting prospects; the method has its limits, and admits different ways of interpretation according to the particular case treated, but it may rightfully take its place among the exploration tools of an oil man.

LITERATURE

[1] L. MIGAUX, "Dix ans d'application de la méthode tellurique", Proc. 3rd W.P.C., The Hague, June, 1951.

[2] V. BARANOV, "Interprétation quantitative des mesues en prospection par courants telluriques", Proc. 3rd W.P.C., The Hague, June, 1951.

DISCUSSION

Mr. GERMAIN-JONES: I appreciate this paper very much, particularly as it has answered a number of questions which bothered me after Mr. Kunetz's paper.

Considering the valuable results this method has given in France and the French colonies, how is it that it seems to have had little application in the U.S.A.?

Mr. MAINGUY: Experimental surveys have been carried out in the U.S.A. and in Venezuela and it has been used for exploration work under the sea. The apparent lack of success is probably due to the fact that the method was asked to provide information beyond its capabilities.

Mr. Wolf: In the U.S.A. the bulk of the prospecting is for small structures at great depth, a problem which is not suited to the telluric method.

Mr. Winkler: What is the cost of a telluric survey compared with the equivalent gravity and seismic surveys?

Mr. Mainguy: About 1.5 times the cost of gravity and about $^1/_3$ or $^1/_4$ the cost of a seismic survey.

GEO-ELECTRICAL PROBLEMS OF THE HYDROLOGY OF WEST GERMAN AREAS *

BY

F. HALLENBACH **

Abstract

The supply of drinking water and water for general use in the towns and communities of Western Germany is in many cases insufficient. In order to eliminate the difficulties in the supply of water, geophysical methods have been applied to a large extent since the end of the war.

The most important hydrological problems, which were solved successfully by geo-electrical measurements, are as follows:

1. Search for, and delimitation of, areas with salty ground water.
2. Investigation of the geological situation in catchment areas for large waterworks, and the finding of suitable places for the establishment of new plants, and in particular:
3. Search for and determination of the thickness and nature of water-bearing sands and gravels and of the relief of the underlying impervious strata.

Some typical examples are presented herewith.

After World War II there was an urgent need for a large supply of drinking water and water for industrial use in towns and communities of Western Germany. This was mainly due to the following facts: insufficient establishment of waterworks of all sizes during the past years, the transfer of numerous industrial plants from the East to the West, and their consequent re-establishment, and the necessity for absorbing several million refugees from all parts of Eastern Europe.

The programme for eliminating the acute shortage in the water supply opened an important field of activity for geophysics, especially geo-electrics. From the end of the war up till now slightly less than 200 large and small hydrological objects have been treated geo-electrically, about 130 of them solely by the teams of the Amt für Bodenforschung in Hanover. In all cases, resistivity methods were applied.

In the following pages a general survey is given of the main types of problems, with characteristic examples of our practical work.

The exploration and delimitation of areas with salty ground water is of the greatest importance. In large parts of North-West Germany salt water is to be found at only shallow depths. There is no need to point out the importance of knowing the position of these areas for the planning of new waterworks, and for the purpose of judging the danger of drawing salt water into the water plants.

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* Presented at the Hanover meeting of the European Association of Exploration Geophysicists, Dec. 4/5, 1952.

** Amt für Bodenforschung, Hanover.

In coastal areas the existence of salty ground water is due to the fact that sea water entered the substratum of the islands and the shore. The underground beds in large parts of the coastal zone are sandy and pervious and allow the sea water to infiltrate inland, for many kilometres in places (Fig. 1). Only where the pressure of fresh water coming from the land equals the hydrostatic pressure of the salt water from the sea is further penetration not possible, and a state of balance can be observed.

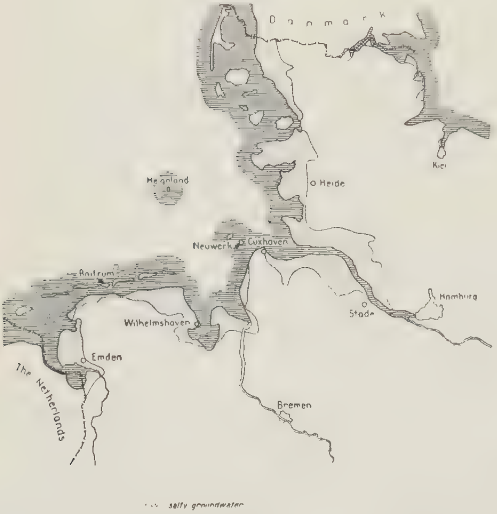

Fig. 1. Areas with salty ground water on the coast of the North Sea, based on well results and geoelectrical measurements (Reports from H. Flathe, H. L. Heck, W. Richter, Th. Weverinck and the author).

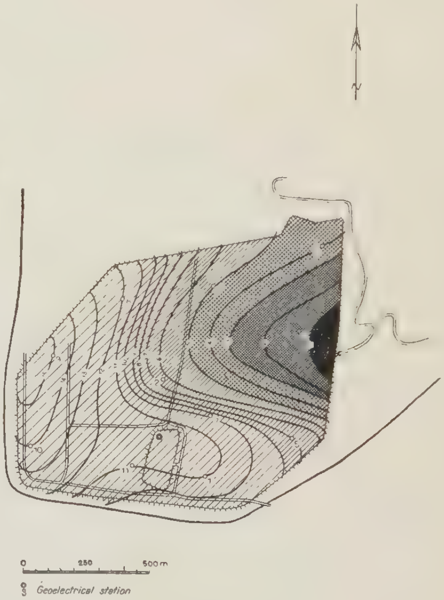

Fig. 2. Geoelectrically determined depth of fresh/salt water-limit on the island of Neuwerk (September, 1949).

Not only near the coastline, but also far into the interior of North-West Germany are large areas known with salty ground water caused by leaching processes. In the Permian formation, the Lower, Middle and Upper Triassic, and in the Upper Jurassic formation, we find salt deposits everywhere in North-West Germany, with the exception of the Münster Basin and the areas of outcropping Variscan folded formations. Tectonic occurrences caused salt masses to be uplifted and brought into contact with the circulating ground water, and we find many salt bodies surrounded by salty water. Sometimes a stretch of salty ground water can be observed in the direction of ground water flow.

The unusually good conductivity of the salt water renders resistivity methods especially suitable for clearing up fresh/salt water problems. Geo-electrical investigations determining the position and thickness of fresh water lenses have been carried out on the three islands of Neuwerk, Baltrum and Helgoland. Extensive measurements in this direction are in full swing in the district of Emden and north of it. In the environs of Wilhelmshaven, investigations of this kind have already been completed.

Up till now only a few geo-electrical explorations have been carried out in those areas with salty ground water where salt deposits exist in the shallow subsoil, but in future geoelectrics will be utilized more than before. It will be far more difficult, however, to solve the problems arising here. The reason for this is, firstly the lower degree of salt concentration in general, compared with the coastal region, and secondly the more complicated tectonics, especially at the borders of the numerous salt domes; and it is often not easy to distinguish geoelectrical effects due to salt water contents from those due to other reasons. The Amt für Bodenforschung has, so far, carried out measurements to determine the depths of fresh/salt water limits at three places (Benthe, Flachstöckheim and Hagenburg). In the last two cases, drilling results to date have confirmed depth values with a fault limit of about 10 %.

As a first example, the result of the investigation on the little island of Neuwerk is given (Fig. 2). A fresh water lens floats on the salt water, the specific gravity of which is, of course, higher than that of the fresh water. Normally, the maximum thickness of this fresh water lens could be expected to lie in the middle of the island. The contour map, however, which gives the depths of the salt water level in metres below surface, shows the highest thickness occurring in the west and south of the island, so that we feel that salt water coming from the East must have pressed the fresh water lens against the western and southern parts of the island.

The advance of the salt water from the east to the middle of the island in such an extraordinary manner may partly be due to a floodgate in the East dam not being tight, so that sea water could occasionally flow into the neighbouring drainage sewers. The main reason for the far-reaching penetration of the salt water, however, is the fact that an old channel, now completely filled up, runs from the east to the middle of the island. Apparently this channel is filled with relatively pervious material, which thus enables the sea water to intrude to such a remarkable distance.

Fig. 3 shows the position and thickness of the fresh water lens on the island of Baltrum. As can be seen, the location of the island's waterworks is quite appropriate. However, it would be advisable to build additional well galleries, if required, further towards the south-east of the island.

Fig. 4 shows the course of the fresh/salt water line in the district of

Wilhelmshaven. The continuous line shows the course at a depth of 20 m., and the dotted line shows it at a depth of 50 m., below the surface. It can easily be seen that the fresh water, coming from the uplands, moves in places far over the salt water. Salt water conditions inside the hatched parts cannot easily be interpreted. The resistivities have values which can be explained by the existence of salty water as well as of clay beds below ground. In the district west of Jever diluvial clay is often found near the surface, and it can therefore be assumed that clay also occurs in the hatched part west of Jever. The situation seems to be different, however, to the north of Sillenstede. Throughout the whole area south of that point, electrical measurements gave no indication of clay in the subsoil, and it is therefore not very likely that clay will be found in the northern hatched part. Apparently salt water intrudes from north to south at shallow depths, following the trend of an old invasion by the sea during the last interglacial period.

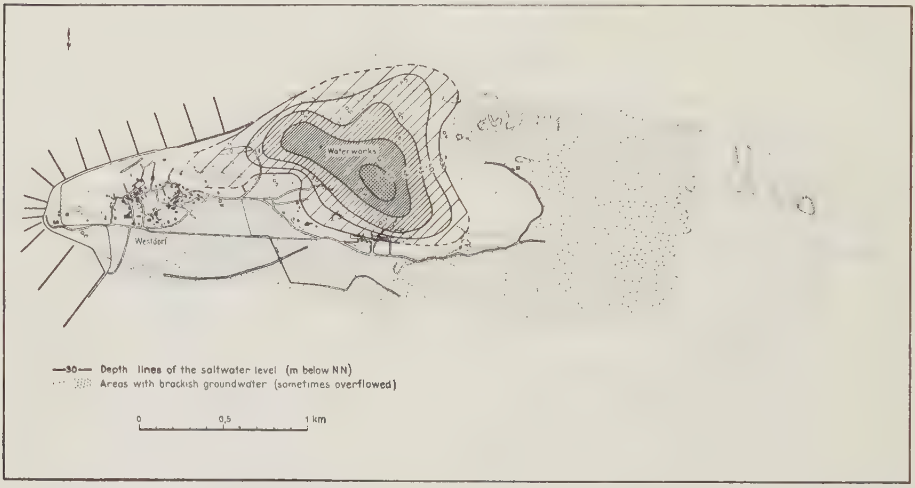
Water works
Westdorf
—30— Depth lines of the saltwater level (m below NN)
Areas with brackish groundwater (sometimes overflowed)
0
0,5
1 km

Fig. 3. Geoelectrically determined depth of fresh/salt water-limit on the island of Baltrum (Spring, 1950). Position and thickness of the fresh water lens.

The Wilhelmshaven waterworks are situated near Feldhausen. As can be seen, the fresh/salt water line runs round the waterworks in the shape of a big half circle. In some places, especially in the area of Sillenstede, where the well galleries of the waterworks nearly reach the village, the fresh/salt water line comes to within one or two kilometres of the water recovery plant. As was established by geoelectrical investigations, there is no immediate danger to the plant. Geoelectrical operations have shown the direction from which possible danger may arise and the points at which observation wells may advantageously be sunk, the chlorine contents in which are registered from time to time.

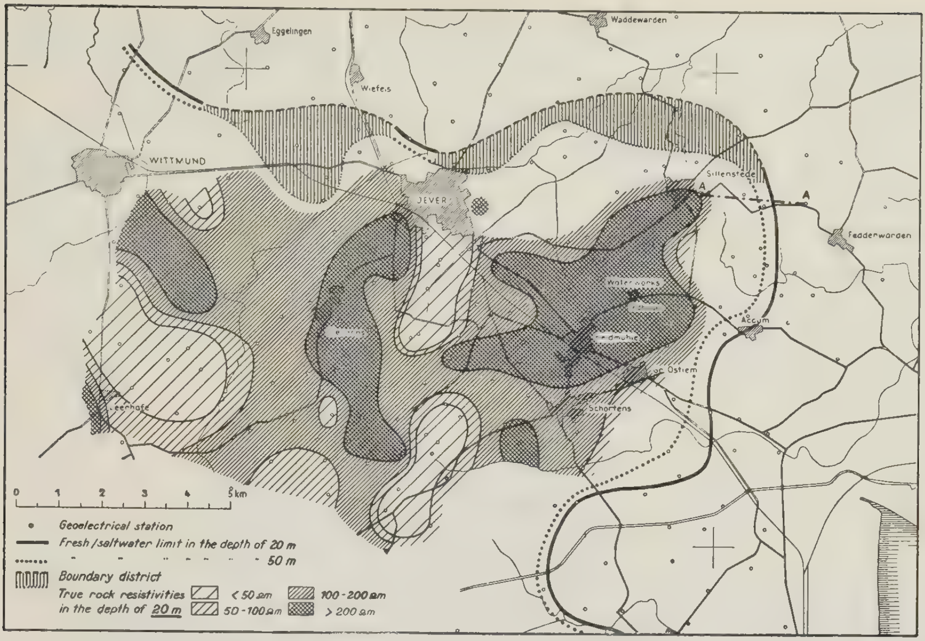

Fig. 4a. The course of the fresh/salt water-limit in the coastal area of Wilhelmshaven, and map of the true rock resistivities at a depth of 20 metres.

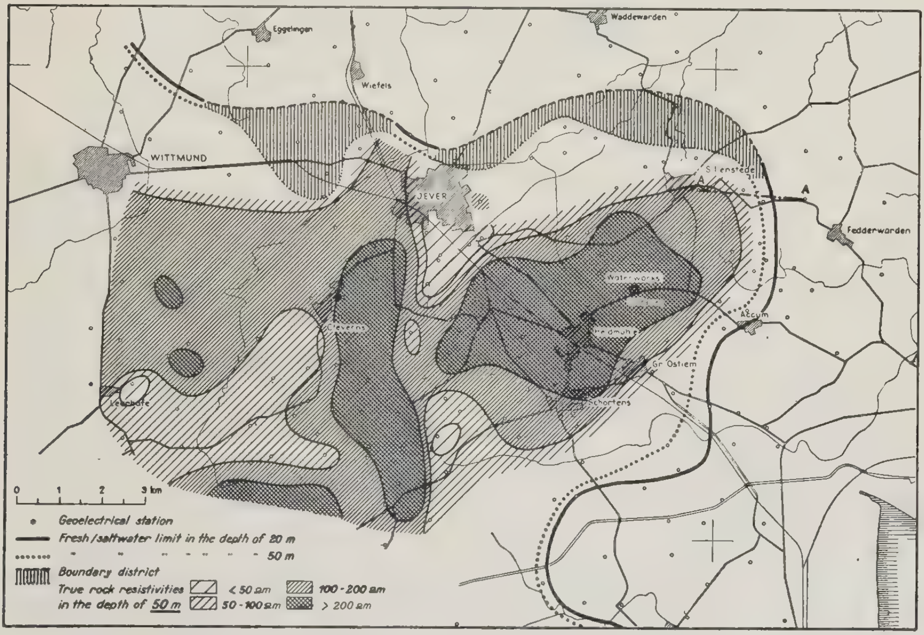

Fig. 4b. The course of the fresh/salt water-limit in the coastal area of Wilhelmshaven, and map of the true rock resistivities at a depth of 50 metres.

Fig. 5 shows four typical resistivity curves from the district south of Sillenstede (Profile A/A). The transition from the fresh water area to the salt water area can clearly be recognized.

The measurements in this area were carried out not only with the object of investigating the fresh/salt water situation in the surroundings of Feldhausen Waterworks, but also for the additional purpose of contributing towards elucidating the geological situation in the underground catchment area of the plant. In particular, a decision was required by geoelectrical methods as to whether hydrologically important clayey rises existed below there which might possibly hinder the ground water from flowing to the well gallery.

With this we come to a further very important and farreaching field of application for geoelectrics, namely, the investigation of underground catchment areas for waterworks. As can be seen from Fig. 4 b, which shows the true rock resistivities at a depth of 50 metres, the resistivities in this particular depth are only to a slight extent below 50 ohmm. Here we have to deal with clay or strongly clayey sands, in any case with impermeable material. Of the three zones with low resistivity, only the area south of Jever would remain if resistivities were to be demonstrated at depths of 70 metres and more. Clay to be found distributed extensively near the surface (see fig. 4a) does not therefore go very deeply, except in the said district. Great parts of the sediments in the catchment area show resistivities of over 200 ohmm., and, judging by experience gained in the North-West German area, they can be regarded as being highly permeable. It is therefore particularly easy to see that the waterworks themselves are not inappropriately situated.

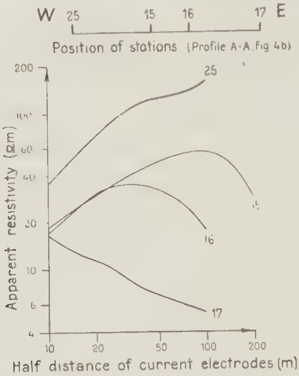

Fig. 5. Resistivity curves at four measurement points located in an east-west profile south of Sillenstede.

One of the main tasks of geoelectrics lies in searching for suitable ground water occurrences and estimating their dimensions. Fig. 6 shows, as an impressive example of these investigations, the result of geoelectrical investigation in the district north of Bremerhaven. Bremerhaven posseses a waterworks near Langen, the output of which should be increased. In the course of preparatory measurements for the enlargement of this plant, a great number of test wells were set up east of Langen, but they were not very successful. Large-scale geoelectrical investigations have now proved that the chance of finding water in sufficient quantities is not very great in the close vicinity of the old water plant; the situation is, however, quite different further east.

Fig. 6 demonstrates the true rock resistivities 40 metres deep. The most important result of geoelectrical investigations is especially clear at this depth. It was possible to trace a far-stretching zone with an average width of 1000 metres, in which resistivities are over 200 ohmm. From the position of this it must be assumed that relatively clear sands are concerned, from which large amounts of water can be produced.

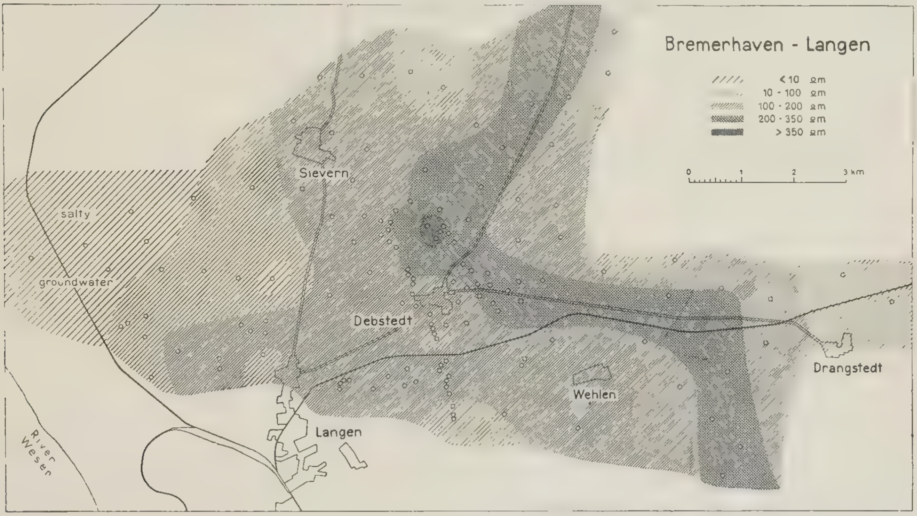

Fig. 6. Map of the true rock resistivities at a depth of 40 metres (north of Bremerhaven).

If the rock resistivity at about 100 m. depth were to be demonstrated, the badly conducting zone would stand out in reverse as a zone with relatively good conductivity. The results of geoelectrical measurements can only be explained by the assumption of a former river bed, approx. 100 metres deep, which is now completely filled up. This old erosion channel is probably filled up at the bottom with clayey material, and the upper 60 metres are probably filled with clear sands. The interesting fact may be pointed out here that, for instance in the channel bend near Debstedt, even the slide and undercut slope of the former river bed can be ascertained by geoelectrical measurements. East of Debstedt, the sand base in the erosion channel dips northeast, and the deepest point of the sand base lies there, on the northern border of the erosion channel. The exact opposite can be found in an east/west cut to the north of Debstedt. Here the base of the clear sands lies deepest in the west of the channel. It can therefore be seen how the river at the bend near Debstedt ran from one side of the valley to the other.

A well, drilled north of Debstedt, in the area with the highest resistivities, has reached the base of the river sands, which were very clean and of a uniform middle grain, at a depth of 56 metres. (Geoelectrically predicted, 60 metres). These investigations near Bremerhaven have not only produced hydrologically interesting results, but, in addition, have also enlarged our geological knowledge of this area in a specially remarkable and highly interesting manner.

The problems which we find in the south of Germany are of an entirely different kind. There, water is taken preferably from the gravels in the mountain valleys or from the glacial and fluvio-glacial sands and gravels, spread out over a vast area in the forelands of the Alps, Black Forest and Swabian Jura.

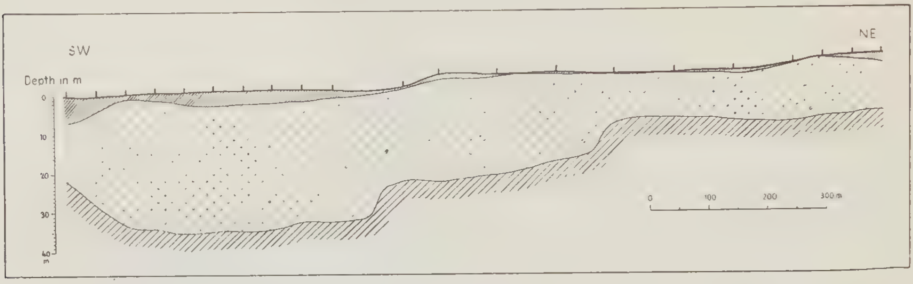

Fig. 7. Geoelectrically determined gravel thicknesses in a valley of the foreland of the Alps.

In accordance with this, geophysical problems are to be summarized normally as follows: the search for valley gravels of sufficient thickness, determination of the relief of impervious strata, and rough estimates of the clay contents to enable permeability to be assessed. Fig. 7 shows an example of this kind of investigation. Here the thickness of the terrace gravels above the marly and finely sandy upper fresh-water Molasse was determined.

From the geoelectrical profile, measured across the course of a valley, it is very easy to see that the valley is divided into three sections, in each of which gravel thicknesses of about 10, 20 and 30 metres occur, and two distinct erosion borders could be traced. A remarkable feature is present in that one of the erosion borders also makes itself perceptible topographically, on the surface, in the shape of a small step. The other erosion border, however, is not recognizable on the surface.

Fig. 8 shows a typical resistivity curve, as usually measured in tasks like the one mentioned above. This particular curve, for instance, was measured during investigations of the underground conditions with regard to the erection of the Argental Barrage in the area north of Lake Constance. The well profile is shown on the sketch. The geoelectrical prediction in this case was confirmed by the well result to a degree of exactness of 1 %. This, of course, is a very exceptional degree of accuracy. Normally, the fault limits were not more than

10-15 % in districts where well results were sometimes available. When there were no wells for comparison, the fault limits were naturally a little higher, about 20 % on the average, but never more than 30 % up till now. The relative depths could, however, even in those cases, be given more precisely than the absolute ones.

In the big drainage channels in the forelands of the Alps, the underlying stratum of the gravel beds consists mostly of clay, marls, or of strongly clayey sands, with good conductivity. Here, the badly conducting gravels are distinguished from the lower deposits in an electrically noticeable manner. Conditions for the use of geoelectrics in the Black Forest, where gravels normally lie on superficially lightly weathered gneisses and granities, are much less convenient. In these parts, geoelectrical measurements result mostly in rough estimates, and, very often, depths cannot be established with the desired correctness. Difficulties also appeared in parts of the Swabian area, where limestone, calcareous tuff or gypsum lie under the gravels, and where the gravel base does not always appear as an interface of electrically different rocks. It is planned to complete the geoelectrical measurements in the future by refraction seismic work.

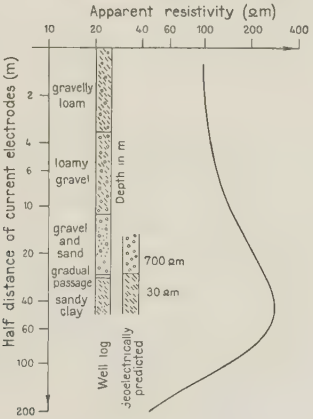

Fig. 8. Well profile and resistivity curves at a place in a fluvio-glacial valley of the foreland of the Alps.

The possibilities offered by geoelectrics are not yet being utilized to the extent which seems practicable and also desirable. This is not because geophysical methods are too little known in circles engaged in the search for ground water. The real reason is rather that the results of geoelectrical projects have not, up till now, always proved satisfactory. Work carried out by outsiders has been particularly disappointing in this respect, and geoelectrical methods have thus been brought into ill repute. So a certain amount of reserve is well understandable. It is to be hoped that there will soon be a change for the better, and that geoelectrics will be given the place in hydrology to which they are entitled.

BEITRAG ZUR INTERPRETATION VON SCHWEREBILDERN MIT HILFE HöHERER ABLEITUNGEN *

VON

B. KOSBAHN **

Abstract

For the treatment of the problems involved in the, interpretation of gravity pictures this paper gives a formula that holds generally for any potential function. It provides an extended applicability of the relation used by Elkins for the computation of the second derivative, and also yields an analogous relation to derivatives of higher order of the gravity field.

This relation has not been utilized to determine in details the course of the derivatives of higher order in a plane, but is merely applied to points of comparatively extreme curvature of the isogams where the differential values present a ratio favourable to the "noise level". By this method the values of the derivatives of higher order will not be determined themselves but only the ratio's responsible for the depth of divergence in comparison with the course of an anomaly of masses replaced by points.

It is shown by examples of intercalated masses that the divergence points are important and by law related to the form and position of the density contrasts themselves.

An analysis of the total gravity picture is made possible by progressing from elements close to the surface to deeper ones. In this way the fundamental features of the earth's crust will be obtained. The application of the analysis process to a gravity anomaly actually measured in Northwest Germany is given.

Die Frage, wieweit es möglich sei, aus theoretisch bekannten Zusammenhängen zwischen den verschiedenen Bestimmungsgrössen eines Schwerefeldes nun auch für die Deutung von Schwerebildern in der Praxis Nutzen zu ziehen, ist besonders bedeutsam geworden, seitdem wir mit Hilfe moderner Gravimeter in der Lage sind, relative Schweremessungen mit erhöhter Genauigkeit durchzuführen und damit auch lokale und schwächere Anomalien zu untersuchen.

Bevor wir das gravimetrische Messmaterial seiner eigentlichen Bestimmung, nämlich der Beurteilung unter rein geologischen Gesichtspunkten übergeben, möchten wir es gerne in einer Form vorzuliegen haben, die uns von vornherein schon einen deutlicheren Bezug zum Aufbau des Untergrundes liefert. Wir möchten versuchen, die in einem Isogammenbild summiert gegebenen Einzel-

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* Presented at the Hanover Meeting of the European Association of Exploration Geophysicists, Dec. 3/4, 1952.

** Seismos GmbH., Hanover/Kirchrode.

wirkungen voneinander zu trennen, tiefere und weiträumige Elemente von solchen zu scheiden, die oberflächennah liegen und nur lokal wirksam sind, und schliesslich möchten wir auch über die Tiefen und Lagerungsformen der einzelnen Massenstörungen Angaben abzuleiten versuchen. Natürlich wird es in erster Linie von der Genauigkeit unserer Messdaten abhängen, wieweit wir eine derartige Analyse von Fall zu Fall führen können.

Aus der Reihe der sich hier bietenden Möglichkeiten hat sich bereits seit einiger Zeit ein Verfahren in der Praxis bewährt, nämlich die Methode der 2. Ableitung. Nach einer Grundformel, die von T. A. Elkins im Jahre 1951 angegeben wurde [1], wird aus dem Verlauf der durch Messung gegebenen

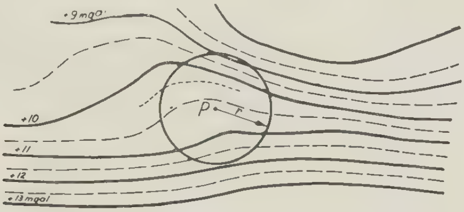

Abb. 1. Isogammenbild (U_z) als Beispiel einer Potentialfunktion
$U: \Delta U = U_{xx} + U_{yy} + U_{zz} = 0$

Mittelfunktion $\bar{U}$ um einen Punkt P in Abhängigkeit vom Radius $\bar{U}(r) = \frac{1}{2\pi} \int_0^{2\pi} U d\varphi$ (bei festem r)

Grundformel: $\bar{U}(r) = U^0 - \frac{r^2}{2!} \cdot \frac{1}{2} U^0_{zz} + \frac{r^4}{4!} \cdot \frac{3}{8} U^0_{zzzz} - \frac{r^6}{6!} \cdot \frac{5}{16} U^0_{6z} + - \dots$

U^0, U^0_{zz}, U^0_{zzzz} u.s.w. sind die Werte für Punkt P.

Fig. 1. Isogam map (U_z) as an example of a potential function
$U: \Delta U = U_{xx} + U_{yy} + U_{zz} = 0$

Mean value $\bar{U}$ about a point P dependent on the radius $\bar{U}(r) = \frac{1}{2\pi} \int_0^{2\pi} U d\varphi$ (bei festem r)

Fundamental formula: $\bar{U}(r) = U^0 - \frac{r^2}{2!} \cdot \frac{1}{2} U^0_{zz} + \frac{r^4}{4!} \cdot \frac{3}{8} U^0_{zzzz} - \frac{r^6}{6!} \cdot \frac{5}{16} U^0_{6z} + - \dots$

are the values at point P.

Vertikalintensität U_z der Verlauf der zweiten Ableitung nach der Tiefenkoordinate z, also der Grösse U_{3z} berechnet und flächenhaft dargestellt. Der Fortschritt, der damit für unsere Problemstellung bereits erreicht ist, beruht darauf, dass die Darstellung einer Schwereanomalie in ihrer 2. Ableitung eine stärkere gegenseitige Trennung der Einzelstrukturen bewirkt, wobei flach liegende Strukturen gegenüber tieferen und regionalen Einflüssen stark zur Geltung kommen, ja manchmal überhaupt erst klar ersichtlich werden. Freilich hängt es von den speziellen tektonischen Verhältnissen und auch von der

Aufgabenstellung im betreffenden Messgebiet ab, inwieweit damit auch für die geologische Interpretation ein günstigerer Ansatzpunkt erreicht wurde.

Um zu untersuchen, ob dieses Verfahren erweiterungsfähig ist und schliesslich auch zu Tiefenberechnungen verwendet werden kann, sei zunächst das Wesentliche des von Elkins angegebenen Zusammenhangs kurz dargestellt und zu einer allgemeinen Formel ergänzt: *Siehe Abb. 1.*

Es handelt sich um eine für jede Potentialfunktion U gültige Beziehung, also unter der Voraussetzung der Laplace'schen Gleichung: $U_{xx} + U_{yy} + U_{zz} = 0$. Liegt der Verlauf einer solchen Potentialfunktion auf einer Ebene x-y vor, dann können wir daraus für irgendeinen Punkt dieser Ebene die Ableitungen dieser Funktion nach der z-Koordinate (wie üblich nach unten gerichtet), d.h. also die Grössen U_{zz}, U_{4z}, U_{6z}, usw. für diesen Punkt aus einer Funktion berechnen, die wir uns folgendermassen bilden:

Wir legen um den Punkt P konzentrische Kreise und bestimmen darauf jeweils den mittleren Wert, den die Funktion U dort annimmt, d.h. wir bestimmen für den Kreis mit Radius r folgenden Wert $\bar{U} = \bar{U}(r)$:

$$\bar{U} = \frac{1}{2r} \int_{0}^{2\pi} U \, d\varphi$$

Damit erhalten wir in Abhängigkeit vom Ringradius r eine Mittelfunktion $\bar{U} = \bar{U}(r)$, deren Werte und Verlauf wir uns irgendwie ermitteln oder aufzeichnen können. Die Genauigkeit, mit der wir den Verlauf dieser Funktion bestimmen können, hängt natürlich davon ab, wie genau unsere Karte der Funktion U selbst der Wirklichkeit entspricht. Übertragen auf die Vertikalintensität U_z einer Schwereanomalie heisst dies, dass die Genauigkeit entscheidend ist, mit der wir unser Isogammenbild durch Messung bestimmt haben. Neben der eigentlichen Messgenauigkeit betrifft dies auch die Zahl der Messpunkte und deren Dichte, die uns gewährleisten muss, dass wir an keiner Stelle Strukturierungen des Schwerebildes von wesentlicher Bedeutung nicht erfasst haben.

Für $r = 0$ nimmt die Mittelfunktion $\bar{U}$ den Wert von U im Punkte P an und wollten wir nun die Funktion $\bar{U}$ als Taylorreihe nach (geraden) Potenzen von r entwickeln, so müssten wir die Differentialquotienten nach r im Punkt P einsetzen. Zwischen diesen und den obenerwähnten Grössen U_{zz}, U_{4z}, U_{6y} besteht aber nun, wie Elkins für U_{zz} angegeben hat und wie sich unschwer verallgemeinern lässt, ein Zusammenhang, der uns die Funktion $\bar{U}$ wie folgt entwickeln lässt:

$$\bar{U}(r) = U^0 - \frac{r^2}{2!} \cdot \frac{1}{2} U^0{}_{zz} + \frac{r^4}{4!} \cdot \frac{3}{8} U^0{}_{4z} - \frac{r^6}{6!} \cdot \frac{5}{16} U_{6z} + - \dots$$

Für den in der Praxis sehr wichtigen zweidimensionalen Fall, in dem wir die Abhängigkeit von der y-Koordinate vernachlässigen können, definieren wir unsere Mittelfunktion folgendermassen:

$$\bar{U}(r) = \bar{U}(x) = \frac{U(+x) + U(-x)}{2}$$

Für die Potenzreihe gilt dann dieselbe Entwicklung, lediglich unter Fortfall der Faktoren $-\frac{1}{2}, -\frac{3}{8}, -\frac{5}{16}$, usw.

Die Funktion $\bar{U}$ wird also durch eine Summe von Parabeln höherer Ordnung dargestellt, wobei die Werte für die höheren Ableitungen im Punkt P die entsprechenden Koeffizienten bilden (mit alterierendem Vorzeichen!) und so Verlauf und Krümmungseigenschaften von $\bar{U}$ bestimmen.

Umgekehrt kann uns dieser Zusammenhang dazu dienen, aus einer ermittelten $\bar{U}$-Kurve oder (gleich auf das Schwerebild übertragen) $\bar{U}_z$-Kurve nun die Werte für höhere Ableitungen zu bestimmen und so zu versuchen, das Schwerebild analog zur zweiten Ableitung nun auch in weiteren höheren Ableitungen darzustellen. Eine derartige Weiterführung ist aber nur sehr beschränkt möglich und wäre auch für eine praktische Analyse von Schwerebildern kaum von Bedeutung. Denn erstens wäre dazu an den meisten Stellen unseres Isogammenbildes die Genauigkeit der $\bar{U}_z$-Funktion nicht ausreichend, um innerhalb des schwach bewegten Verlaufs dieser Funktion noch Krümmungen höherer Ordnung berechnen zu können, und zweitens würde in Darstellungen von höheren Ableitungen mit zunehmendem Masse nur eine Herausarbeitung von sehr lokalen und oberflächennahen Strukturen erfolgen. Es würde eine Verschiebung der erkennbaren Anomalien nach der Oberfläche zu erfolgen und in vielen Fällen könnte dies eher zu einer Verdeckung der interessierenden Massenstörungen führen.

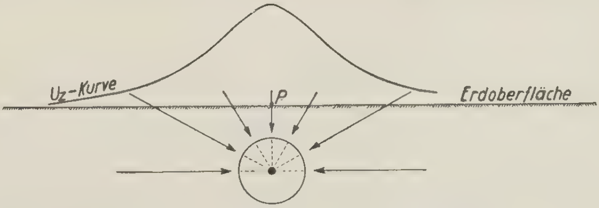

Abb. 2. Wirkung einer homogenen kugelformigen Dichtestörung im Aussenraum: Radialsymmetrisch, von einem Divergenzpunkt ausgehend ($U_z = \bar{U}_z$ für Punkt P).

Fig. 2. External effect of a homogeneous buried sphere: Radially symmetrical around a source ($U_z = \bar{U}_z$ for point P).

Anders liegt der Fall jedoch, wenn wir unsere Überlegungen aus ausgesprochene Extremstellen des Schwerebildes beschränken, d.h. auf Stellen, an denen entweder bereits im U_z-Bild ein relatives Maximum oder Minimum vorhanden ist oder sich andeutet und durch einen relativen Extremwert in den Krümmungsverhältnissen von $\bar{U}_z$ bestätigt und genauer fixiert wird. An solchen Stellen können wir sagen, dass wir uns über einem wirksamen Störzentrum selbst befinden, und weiterhin werden an diesen Extremstellen die Differenzbeträge im $\bar{U}_z$-Verlauf noch am ehesten Beträge aufweisen, die bis zu einem gewissen Grad auch noch die Untersuchung höherer Krümmungen gestatten.

Wir reduzieren also, zumindest in erster Näherung, unser Problem auf das einer punktförmigen Massenstörung. Wie wir sehen werden, liegt die Berechtigung hierzu ganz allgemein in den Eigenschaften des Schwerkraftfeldes begründet. Bereits für die Wirkung einer homogenen kugelförmigen Störmasse gilt ja der Satz, dass sie im Aussenraum d.h. also auf der Erdoberfläche, worauf wir unsere Überlegungen ja ansetzen, derart ist, als käme sie ganz von dem mit der Gesamtmasse belegten Mittelpunkt her. *Siehe Abb. 2.*

Die Schwereanomalie kann als Wirkung eines Punktes von bestimmter Tiefe und bestimmter Intensität aufgefasst werden, den wir Divergenzpunkt nennen können, weil sich die verlängert gedachten Kraftlinien des Aussenraums gleichsam in ihm schneiden, er somit ein Unstetigkeitspunkt des Kraftfeldes wird, soweit es durch den Aussenraum bestimmbar wird. Tiefe und Intensität des Divergenzpunktes bestimmen den Schwereverlauf an der Erdoberfläche nach den bekannten Formeln:

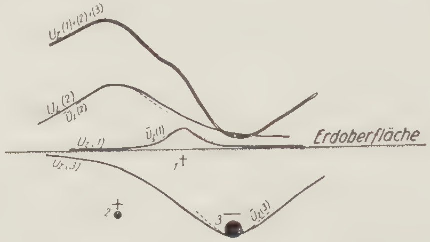

Abb. 3. Summation von Einzelwirkungen, Extremwerte der Krümmung im U_z-Verlauf über den Divergenzpunkten.

Fig. 3. Sum total of individual effects. Extreme values of the curvature in the U_z curve above the sources.

$$U_z = U^0_z . \frac{1}{\sqrt{\left[1 + \left(\frac{r}{z_0}\right)^2\right]^3}}$$

$$r = \sqrt{x^2 + y^2},\ Z_0 = \text{ Tiefe des Divergenzpunktes, } U^0_z = U_z(P)$$

bzw. für den 2-dimensionalen Fall:

$$U_z = U^0_z . \frac{1}{1 + \left(\frac{r}{z_0}\right)^2}\ r = x$$

Diese Grössen sind es auch letztlich, die im idealen Falle aus dem Schwereverlauf abgeleitet werden können. Für den Punkt P über dem Divergenzpunkt gilt $U_z(r) = \bar{U}_z(r)$, Schwerefunktion und Mittelfunktion sind also für den Scheitelpunkt identisch, und wir werden also an den zu untersuchenden Stellen unsere jeweilige $\bar{U}_z$-Kurve zur oben angegebenen 2-parametrigen Kurvenschar in Beziehung setzen und daraus Tiefe und Intensität des Divergenzpunktes zu bestimmen suchen. Die Ungenauigkeiten im Verlauf der $\bar{U}_z$-Funktion werden sich in entsprechenden Unsicherheiten unserer Tiefenangaben wiederfinden.

Das Zusammenwirken mehrerer Divergenzpunkte wird aus Abb. 3) an einem Beispiel veranschaulicht. Durch Addition der Einzelwirkungen $U_z(1)$, $U_z(2)$, $U_z(3)$ ergibt sich der Schwereverlauf im Profil. Die Divergenzpunkte 2) und 3) machen sich bereits im U_z-Profil deutlich durch ein relatives Extremum bemerkbar, während die Wirkung von 1) derart überlagert ist, dass erst durch Untersuchung der Mittelfunktion $\bar{U}_z$ an dieser Stelle sich ein Maximum klar abzeichnet. An den Extremstellen sind im Vergleich zu den eigentlichen singulären U_z-Kurven auch die Kurven der entsprechenden Mittelfunktionen eingezeichnet. Zwischen beiden Kurven bestehen Abweichungen, eben infolge der gegenseitigen Überlagerung der Einzelwirkungen, wir sehen aber auch, dass diese Abweichungen umsoweniger ins Gewicht fallen, je mehr wir uns auf den unmittelbaren Scheitelbereich beschränken können. Die daraus abgeleiteten Tiefenwerte und die Anordnung der Divergenzpunkte im Untergrund werden uns dann doch ein der Wirklichkeit im Wesentlichen nahe kommendes Bild liefern.

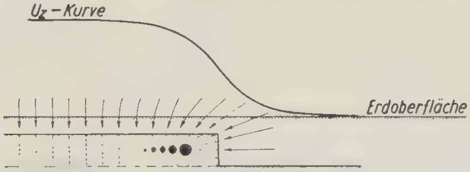

Abb. 4. Horizontale Dichtestörung (Verwerfung). Wirkung im Aussenraum von Divergenzenpunkten herrührend, die am Rande liegen (mit Extremwert).

Fig. 4. Horizontal density discontinuity (fault). External influence arising from sources lying on the edge (with extreme value).

Vom gegenseitigen Abstand der Divergenzpunkte hängt es ab, bis zu welcher Schärfe sie sich voneinander trennen lassen, und bei einer kontinuierlichen Verteilung von Divergenzpunkten könnte es überhaupt fraglich erscheinen, ob mit diesem Verfahren ein Erfolg erzielt werden kann. Aber auch bei kontinuierlichen oder linienförmigen Anordnungen von Divergenzpunkten sind meistens irgendwelche Extremwerte vorhanden, deren Einzelwirkung überwiegt. In Abb. 4 sei dies an einer horizontalen Dichtestörung veranschaulicht. Die Kraftlinien lassen qualitativ das Wesentliche des Schwereverlaufs erkennen. Zunächst verlaufen sie parallel, führen in ihrer Verlängerung also zu keinem Divergenzpunkt, der die U_z-Kurve krümmungsmässig beeinflussen könnte. Erst gegen den Rand der Störung zu weichen sie aus einander und ergeben Divergenzpunkte mit zunehmenden Intensitäten, die sich zu einem Extremwert steigern. Sucht man diesen Extremwert auch in den dazugehörigen $\bar{U}_z$-Kurven auf, so kann man auch hier wieder angenähert eine punktförmige Wirkung als Vergleich ansetzen und die Tiefe des Divergenzpunktes bestimmen. Dessen Einzelwirkung liesse sich aus dem Schwereverlauf eliminieren, sodass als Restbild der Verlauf einer verkürzten Scholle übrig bliebe, die weiter untersucht werden könnte. Als Ergebnis würde eine Divergenzlinie auftreten, die uns als Symmetrielinie der Massenstörung Aufschluss über deren Richtung und Lagerung geben kann.

Diese Methode der Reduzierung auf punktförmige Massenstörungen lässt sich auch auf andere, insbesondere kontinuierliche Divergenzpunktverteilungen erweitern, doch lassen sich viele Beispiele der Praxis, soferne überhaupt die Genauigkeitsansprüche erfüllt sind, in dieser einfachen Weise bereits behandeln.

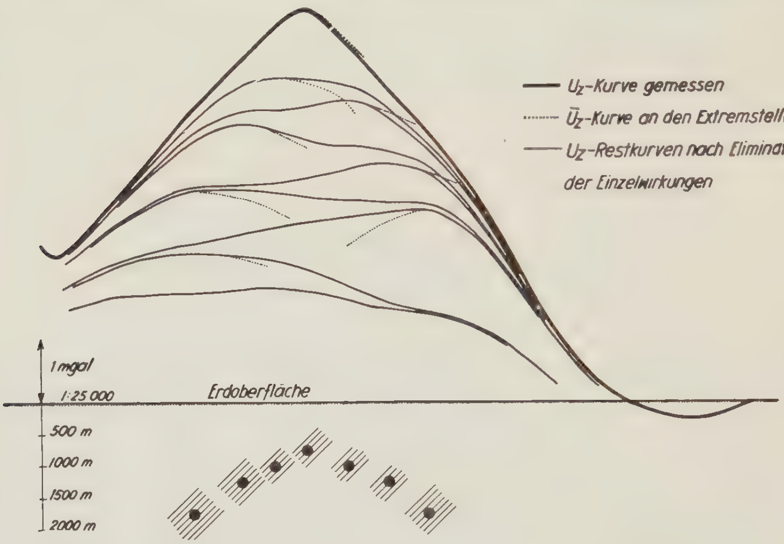

Abb. 5. Struktur in N.W. Deutschland — Structure in N.W. Germany.
Analyse der U_z-Profils — Analysis of U_z Cross section.

Abb. 5 zeigt ein Beispiel der Anwendung dieser Untersuchungsmethoden in der Praxis an einer Schwerestruktur von NW-Deutschland. Die stark ausgezogene Linie zeigt die gemessenen Schwereunterschiede im Profil an, die dünnen Linien jeweilig die Restkurven nach Elimination von Einzelwirkungen im Fortschreiten von oberflächennahen zu tieferen Elementen. Das System der Divergenzpunkte gibt uns einen Anhalt für das die Struktur aufbauende tektonische Grundgerüst. Wir sehen, dass es sich bei dieser Struktur nicht um einen einfachen, eine bestimmte Schichtenfolge gleichmässig aufwölbenden antiklinalen Bau handeln kann. Einem solchen Bau könnte keine solche Symmetrielinie zugeordnet werden, die ein deutliches Zusammenwirken von zwei verschiedenen Richtungen bzw. von zwei getrennten Divergenzpunktbereichen erkennen lässt. Man würde hier eher sagen können, dass zwar dem linken ansteigenden Divergenzpunktbereich ein entsprechender Schichtanstieg mit

Aufwölbungszentren in den angegebenen Tiefenbereichen zuzuordnen wäre, dass den rechts erkennbaren Divergenzpunkten aber noch andere tektonische Elemente wie Mächtigkeitsänderungen oder andere Diskordanzen zukämen. Freilich kann das Schwerebild hier keine weiteren Aussagen liefern, aber auch wenn wir an dieser Grenze Halt machen müssen, können wir der geologischen Interpretation doch ein Material zur Verfügung stellen, das einen unmittelbareren Bezug zum Aufbau des Untergrundes liefert als es mit dem Schwereverlauf allein möglich wäre. Es ist interessant, hiermit die aus reflexionsseismischen Messungen bzw. aus Tiefbohrungen erhaltenen geologischen Aufschlüsse zu vergleichen. Hiernach handelt es sich bei dieser Struktur um eine Aufwölbung, die zunächst einen starken Anstieg von Schichten der Kreidefolge mit sich bringt, während der Verlauf der darunter liegenden jurassischen und präjurassischen damit nicht konkordant ist und erst später zu einem Kulminationspunkt bzw. Abbruch führt.

Für die Genehmigung, diese Arbeit zu veröffentlichen bin ich zu besonderem Dank Herrn Dr. Lückerath von der Seismos G.m.b.H., sowie Herrn Dr. Schleusener für wertvolle Hinweise und Anregungen, verpflichtet.

LITERATUR

THOMAS A. ELKINS, „The Second Derivate Method of Gravity Interpretation", Geophysics XVI, 1951, S. 29-50.

DISKUSSION

Herr ROSENBACH: In dem von Ihnen gezeigten Beispiel sind 9 Kurven gezeichnet, aber nur 7 Divergenzpunkte angegeben, worauf beruht das?

Herr KOSBAHN: Es sind 8 Mittelfunktionskurven gezeichnet, wobei jedoch die unterste wegen der nur noch geringen und unsicheren Differenzbeträge nicht mehr ausgewertet wurde.

Herr ROSENBACH: Was hat man mit diesen Divergenzpunkten für die geologische Interpretation der geophysikalischen Messergebnisse gewonnen, die ja letztlich der Sinn unserer Arbeit ist?

Herr KOSBAHN: Die Divergenzpunktverteilung ist gleichsam das räumliche Gerüst, der Kern, aus dem heraus eine bestimmte Massenverteilung schweremässig wirksam ist. Für die weitere Interpretation ist es von sehr wesentlicher Bedeutung, zunächst einmal dieses Charakteristikum einer Schwerewirkung herauszuarbeiten.

Herr BARANOV: Comment voulez-vous constituer une véritable anticlinale après avoir déterminé les lignes?

Herr KOSBAHN: Zunächst handelt es sich darum, das gravimetrische Messmaterial so umzuformen und zugleich zu veranschaulichen, dass aus der Verteilung und Anordnung der Divergenzpunkte die räumliche Lagerung der Massenstörung direkt ersichtlich wird. Es ist eine weitere Frage, wieweit dann die erhaltene Anordnung einem vermutbaren antiklinalen Bau entsprechen kann oder nicht.

Herr KUNZ: Die Umwandlung wird in Wirklichkeit verfrührerisch, da der Divergenzpunkt nur der Mittelpunkt der störenden Masse ist, die so oder so begrenzt sein kann. Der Geologe sucht aber immer diese Grenzen und wird enttäuscht sein, wenn er eine Grenze in anderer Tiefe findet.

Herr KOSBAHN: Das ist das Wesentliche der über Tage ausgeführten Gravimetermessungen, dass aus ihnen nicht direkt Angaben über Schichtgrenzen abgeleitet werden können. Dazu müssen erst Annahmen über bestimmte Dichteunterschiede und damit Massenausdehnungen kommen, die aber dann erst richtig angesetzt werden können, wenn die Mittelpunkte d.h. Divergenzpunkte der Lage und Tiefe nach bekannt sind.

Herr SCHLEUSENER: Der entscheidende Nutzen einer solchen Darstellung ist, dass man erkennen kann, dass es keine einfache Antiklinale im Beispiel sein kann, dieses Verfahren gibt nicht das geologische Bild, sondern die Grundlage dafür, dass das Error und Trial-Verfahren beginnen kann, wenn die sonstigen Verhältnisse geeignet sind.

Herr JUNG: Dieses Verfahren ist also etwas schärfer als die Faustregel nach der Halbwertsbreite. Das ist ein Vorteil, aber auch der einzige, alles andere ist mathematische Phantasie.

Herr SCHLEUSENER: Es ist doch ein Vorteil, wenn man entscheiden kann, dass hier keine einfache Antikline vorliegt und eine solche Entscheidung gehört doch nicht ins Reich der Phantasie. Die Zukunft wird lehren müssen, ob dieses Verfahren für die Praxis wertvoll ist. M.E. kann das Verfahren auch bei der Deutung der 2. Ableitung des Schwerepotentials von Vorteil sein und z.B. verhindern, einem Minimum in U_{zzz} über der Mitte einer Platte geologische Bedeutung beizumessen.

Herr BARANOV (vom Präs. übersetzt): Können die Punkte gedeutet werden als eine Schicht, die schwerer ist gegenüber den hangenden und liegenden Schichten und kann diese Schicht als Rand einer Antiklinale angesehen werden?

Herr KOSBAHN: Eine derartige Deutung ist möglich und müsste genauer untersucht werden.

Herr KUNZ: In diesem Beispiel wurde nur mit positiven Divergenzpunkten gearbeitet. Selbstverständlich müsste man auch negative zulassen und so könnte man aus diesem Bild ohne weiteres eine Antiklinale herauslesen weshalb ich vor der Anwendung dieses Verfahrens dringend warnen möchte.

Herr KOSBAHN: In den Krümmungswerten sind Maxima stets mit Minima verbunden, aber in bestimmter Gesetzmässigkeit und bestimmtem Abstand, sodass eine Willkürlichkeit stark eingeschränkt ist. Im angegebenen Beispiel ist die Gefahr einer derartigen Vieldeutigkeit jedoch nicht gegeben.

THE INITIAL ADJUSTMENTS OF VERTICAL VARIOMETERS *

BY

J. M. BRUCKSHAW **

ABSTRACT

Using a comprehensive theory of the vertical force variometer, it is shown that the mean of the two readings taken in azimuths 180 degrees apart only eliminates the error of misorientation and of inclination of the knife edge if these factors are sufficiently small. The necessary accuracy in the 180 degree rotation and in the readjustment of the levels are investigated and a practical test is developed to allow the initial adjustments to be determined. Finally, a brief description of a new variometer tripod is given.

INTRODUCTION

The simple theory of the vertical force variometer of the Schmidt type is well known and it refers to a magnet pivoted upon a horizontal knife edge lying in the magnetic meridian, so that the magnet can swing in the vertical eastwest plane. Deviations of the axis of the magnet from the horizontal position are observed with an optical system and these deviations can be related directly to changes in the vertical component of the magnetic field. In practice, a compass is used to recover the magnetic east-west plane for the plane of oscillation of the beam and levels are provided so that the knife edge can be made horizontal and they also serve to give a standard of direction from which the deflections of the beam are measured. Due, however, to certain mechanical limitations, and also to errors arising in the manipulation of the equipment, the ideal conditions are rarely obtained, and from a single observation in one azimuth alone the computed field may include serious errors. By making two observations at each station, in azimuths separated by 180°, and using the mean reading the errors are substantially reduced but they are not completely eliminated. The magnitude of the error in the calculated field depends upon the total error in orientation and also in levelling. Generally, it is easy to carry out the manipulation well within the required tolerance but mechanical limitations may arise so that, even when the compass is accurately used, the magnet may not, in fact, swing in the east-west plane. Further, it is obvious that the relation between the direction of the knife edge and the reference plane defined by the levels when set at some standard reading is somewhat arbitrary.

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** Imperial College of Science and Technology, London.

It is worth noting that two standard directions of reference are possible with the usual design of variometer. One is related to the axis of rotation and the other is a standard attitude between the instrument case and the horizontal plane at the station, this attitude being recovered by setting the levels at a standard reading. It is possible to make the axis of rotation vertical by adjusting the footscrews so that the levels show the same reading in all azimuths. This adjustment would appear ideal since, in theory, it can be recovered independent of any change of the levels. The angle between the knife edge and the plane normal to the axis of rotation would then be the constant inclination of the knife edge and the normal plane would supply a standard reference direction for the measurement of the tilt of the magnetic axis of the beam. In use this method has proved unsatisfactory because the magnetometer and the tripod head, which carries the turntable and so defines the axis of rotation, are separate components. Thus, unless the fit of the magnetometer on to the tripod head is perfectly reproducible the axis of rotation will define a different direction in the variometer at each station. In particular, dust between the two mating surfaces will lead to unspecified and irreproducible angles between the two parts and a simple calculation shows that a particle of size 10^{-3} cm. will give relative tilts of the order of 20 sec. of arc, a tilt readily appreciated on the levels fitted on these instruments. It would appear that it is better to rely upon the levels to establish a plane of reference. It is a matter of experience, however, that the direction specified by a bubble level changes through a number of effects, usually associated with temperature variations, and so this datum is not ideal. It can be shown, however, that for the level parallel to the knife edge, the effect of such changes can be eliminated provided the tilt of the knife edge does not exceed a certain maximum value. The calculated value of the field is thus only in error by an amount which depends upon the longitudinal level, i.e. the level parallel to the plane of oscillation of the magnet. To illustrate the various factors involved, and to show how the error in the initial adjustments can be determined, it is necessary to consider the general theory of the instrument.

General Theory

(a) Couples acting on magnet swinging in an inclined plane.

Let the vertical plane containing the knife edge make an angle α (Fig. 1) with the magnetic meridian and, in this plane, let the knife edge make an angle β with the horizontal, this angle being positive when downwards. These angles will ultimately be the small errors of orientation and levelling respectively. The vertical and horizontal fields Z and H can be resolved into components parallel and perpendicular to the plane of oscillation of the magnet (abreviated to P.O.). The latter components act parallel to the knife edge and do not influence the equilibrium of the magnet, only those components in the P.O. being effective. The components are tabulated below.

From vertical field.

Component parallel to knife edge $= Z \sin \beta$

Component parallel to intersection of P.O. and vertical plane containing knife edge $= Z \cos \beta$

From horizontal field

Component parallel to knife edge $= H \cos \alpha \cos \beta$

Component parallel to intersection of P.O. and vertical plane containing knife edge $= - H \cos \alpha \sin \beta$

Component parallel to intersection of P.O. and horizontal plane $= - H \sin \alpha$

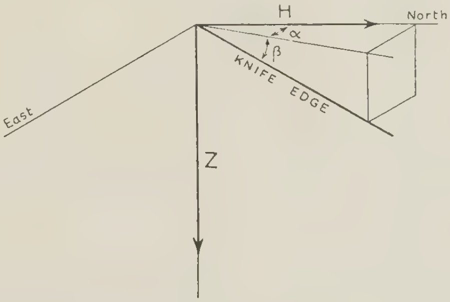

Fig. 1. Definition of misorientation and tilt of the knife edge.

The magnetic fields acting on the poles of the magnet and in the P.O. are shown in Fig. 2, together with the force due to gravity on the mass m, this last being reduced by cos β due to the inclination of the plane.

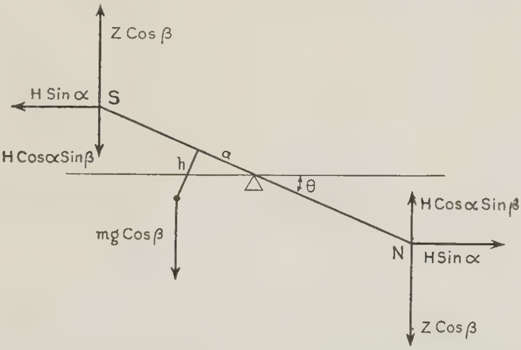

Fig. 2. The components of the field acting on the variometer magnet.

(b) Condition of equilibrium.

If a is the displacement of the mass centre from the knife edge and along the magnetic axis and h its displacement perpendicular to this axis, then the equation of equilibrium is given by

$$M\,(Z\cos\beta - H\cos\alpha\sin\beta)\cos\vartheta - M\,H\sin\alpha\sin\vartheta = m\,g\cos\beta\,(a\cos\vartheta + h\sin\vartheta)$$

or

$$Z\cos\beta - H\cos\alpha\sin\beta - H\sin\alpha\tan\vartheta = mg\cos\beta\,(a + k\tan\vartheta)\,/\,M \quad (1)$$

where ϑ is the inclination of the magnet and M the magnetic moment. In the vertical variometer the inclination ϑ is small and is observed by a beam of light moving over a scale after reflection from a mirror fixed to the magnet. Thus

$$\tan\vartheta = (n_1 - n_0)\,/\,2f = n\,/\,2f$$

where n_1 is the equilibrium reading on the scale, n_0 the reading corresponding to the horizontal position of the magnet and f the effective distance between mirror and scale. It should be noted that the reading n_0 cannot be observed directly because the magnetic axis usually makes a small unknown angle with the geometrical axis. Expressed in terms of scale divisions on the optical system, however, this angle may correspond to several divisions. Following the usual simple theory, the horizontal position of the beam will correspond to a vertical field Z_0' given by

$$Z_0'\cos\beta - H\cos\alpha\sin\beta = (m\,g\,\alpha\cos\beta)\,/\,M.$$

This equation defines the field in which the magnet would lie with its axis horizontal if the misorientation were α, the tilt of the knife edge β and the horizontal field were H. Due to faulty manipulation the errors in setting up the instrument on one occasion will not be recovered precisely at a second point, and in any case the value of H will vary locally. Accordingly, this definition is vague and impracticable and it is preferable to define Z_0 as the vertical field in which the magnet axis would be horizontal if the instrument were in perfect adjustment, i.e. $\alpha = \beta = 0$, in which case the above equation is replaced by

$$Z_0 = m\,g\,a\,/\,M.$$

Then from (1)

$$(Z - Z_0)\cos\beta - H\cos\alpha\sin\beta - H\sin\alpha .\, n\,/\,2f = m\,g\,h\cos\beta .\, n\,/\,2Mf \quad (2)$$

Again, with conditions of perfect levelling etc.

$$\delta Z = Z - Z_0 = m\,g\,h\,n\,/\,2Mf = \varepsilon\,n$$

where ε is the change in the magnetic field necessary to alter the reading by one scale division (s.d.). Substituting in (2), dividing by $\cos\beta$ and, since the errors of adjustment are small, replacing $\cos\alpha$ and $\cos\beta$ by unity in the relatively small terms in which they occur, leads to the equation

$$\delta Z = (\varepsilon + H\sin\alpha\,/\,2f)\,n + H\sin\beta.$$

Thus the errors of adjustment result in a scale value modified by the misorientation together with the addition of a term involving the tilt of the knife edge. Both these modifications depend upon the horizontal field. This formula permits an estimate of the precision of levelling etc. required to obtain any given accuracy from a single observation. As a general rule the sensitivity is known to 0.1 gamma / s.d., corresponding to an accuracy of 1 part in 10 ε, and hence the change due to misorientation must be less than 0.05 gamma / s.d. in order not to influence the results to this accuracy, i.e.

$$\sin \alpha \leqslant f / 10\,\mathrm{H}$$

a condition independent of the scale value but becoming more stringent with increasing H. Taking H as the maximum value of 35,000 gamma and with $f = 650$ s.d., then

$$\alpha \leqslant 1.9 \times 10^{-3} \quad \text{rad.} = 0.11 \text{ degrees.}$$

Alternatively, a given accuracy of (say) 1 in 200 may be required in which case

$$\alpha \leqslant \quad 2\, f\, \varepsilon / 200\ \mathrm{H}.$$

giving, when $\varepsilon = 30$ gamma / s.d.,

$$\alpha \leqslant 5.6 \times 10^{-3} \quad \text{rad.} = 0.32 \text{ degrees.}$$

For greater sensitivities, or for higher accuracies, the limiting value of α will be smaller. The term involving the inclination of the knife edge must obviously be less than the field equivalent of 0.1 s.d., so

$$\sin \beta \leqslant \quad \varepsilon / 10\ \mathrm{H}$$

and, with the values already used and which will be used in all other numerial examples unless otherwise specified, the condition

$$\beta \leqslant \quad 8.6 \times 10^{-5} \quad \text{rad.} = 18 \text{ sec. of arc}$$

must be satisfied.

The high precision of adjustment revealed by this analysis can be materially reduced if two readings in azimuths 180° apart are taken. The instrument is rotated about a nearly vertical axis and, before the second reading is taken, the levels are adjusted to the same settings as they had in the first azimuth. If the first reading n is made with a misorientation α, then the second reading n′ will correspond to an orientation $(180 + \alpha)$ so that the two equations of equilibrium are

$$\left.\begin{aligned} \delta \mathrm{Z} \cos \beta - \mathrm{H} \cos \alpha \sin \beta - (\mathrm{n\ H} \sin \alpha) / 2\, f = \varepsilon\, \mathrm{n} \cos \beta \\ \delta \mathrm{Z} \cos \beta + \mathrm{H} \cos \alpha \sin \beta + (\mathrm{n' H} \sin \alpha) / 2\, f = \varepsilon\, \mathrm{n'} \cos \beta \end{aligned}\right\} \qquad (3)$$

Adding and subtracting these, and putting $\mathrm{F} = \mathrm{H} / 2\, f$, gives

$$\left.\begin{aligned} 2\, \delta \mathrm{Z} \cos \beta + (\mathrm{n'} - \mathrm{n})\, \mathrm{F} \sin \alpha = (\mathrm{n'} + \mathrm{n})\, \varepsilon \cos \beta \\ 2\, \mathrm{H} \cos \alpha \sin \beta + (\mathrm{n'} + \mathrm{n})\, \mathrm{F} \sin \alpha = (\mathrm{n'} - \mathrm{n})\, \varepsilon \cos \beta \end{aligned}\right\} \qquad (4)$$

which, on solving for $(\mathrm{n'} + \mathrm{n})$ and $(\mathrm{n'} - \mathrm{n})$, yield

$$\left.\begin{aligned} (\mathrm{n'} + \mathrm{n}) = 2\, (\varepsilon \cos^2 \beta\, \delta \mathrm{Z} + \mathrm{F\,H} \sin \alpha \cos \alpha \sin \beta) / (\varepsilon^2 \cos^2 \beta - \mathrm{F}^2 \sin^2 \alpha) \\ (\mathrm{n'} - \mathrm{n}) = 2 \cos \beta\, (\varepsilon\, \mathrm{H} \cos \alpha \sin \beta + \mathrm{F} \sin \alpha\, \delta \mathrm{Z}) / (\varepsilon^2 \cos^2 \beta - \mathrm{F}^2 \sin^2 \alpha) \end{aligned}\right\} \qquad (5)$$

THE ERRORS AND THEIR SOURCE

From the first of equations (5)

$$\delta z = \left(\varepsilon - \frac{H^2 \sin^2 \alpha}{4 f^2 \varepsilon \cos^2 \beta}\right) \frac{n' + n}{2} - \frac{H^2 \sin \alpha \cos \alpha \sin \beta}{2 f \varepsilon \cos^2 \beta} \qquad (6)$$

Since, with the accuracy of levelling and the construction of the instrument, $\cos^2\beta$ can be replaced by unity, the apparent change in the scale value again depends upon the misorientation but now it involves the square of a small quantity. Thus, if the scale value is to be changed by less than 0.1 gamma/s.d.

$$\sin \alpha \leqslant \left(f^2 \varepsilon / 5 H^2\right)^{\frac{1}{2}}$$

which with the previous values gives $\alpha \leqslant 2.6$ degrees. On the basis of a permissable error of 1 in 200, the corresponding formula is

$$\sin \alpha \leqslant f \varepsilon \sqrt{2} / 10 H$$

or $\alpha \leqslant 4.5$ degrees for the standard values used above. These permissable misorientations are very much larger than those which apply when the reading in one azimuth only is used, but they also become smaller as the required accuracy is increased and, in the last case, as the sensitivity increases. Thus for an accuracy of 1 in 400 and a scale value of 10 gamma/s.d., the value of α must be less than 1.1 degree.

Since the effect of tilt of the knife edge is expressed by the final term of (6) it would appear that this factor is less significant. Putting the cosines of small angles equal to unity, for this term to be less than $\varepsilon/10$

$$\sin \beta \leqslant 2 f \varepsilon^2 / 10 H^2 \sin \alpha$$

a criterion which becomes less stringent as the error of orientation is decreased. Thus, with the standard values and $\alpha = 2°$, then $\beta \leqslant 9.4$ min. of arc, and with $\alpha = 4.5°$, $B \leqslant 4.2$ min. For a scale value $\varepsilon = 10$ gamma/s.d. and $\alpha = 1.1°$ $\beta \leqslant 1.9$ min. This apparent improvement, however, requires further consideration, since the rotation through 180° does not automatically give the same tilt of the knife edge in the two azimuths unless the axis of rotation is vertical. The instrument must be levelled before each reading and so errors of adjustment will still be involved.

ACCURACY OF THE 180° ROTATION

In the previous treatment it has been assumed that the rotation was 180° precisely. In practice the azimuths will be $(\alpha - \delta \alpha)$ and $(180 + \alpha + \delta \alpha)$ where α may be regarded as the mean error in orientation and $2 \delta \alpha$ the error in the rotation. To an adequate approximation, with $\cos \alpha$ and $\cos \beta$ equal to one, equations (3) become

$$\delta Z - H \sin \beta - n F (\sin \alpha - \sin \delta \alpha) = \varepsilon n$$
$$\delta Z + H \sin \beta + n' F (\sin \alpha + \sin \delta \alpha) = \varepsilon n'$$

whence

$$2 \delta Z + (n' - n) F \sin \alpha + (n' + n) F \sin \delta \alpha = \varepsilon (n' + n)$$
$$2 H \sin \beta + (n' + n) F \sin \alpha + (n' - n) F \sin \delta \alpha = \varepsilon (n' - n)$$

which are identical with (4) if ε is replaced by $(\varepsilon - F \sin \delta \alpha)$. Since the 180° rotation is made between stops which can be adjusted critically, the condition $F \sin \delta \alpha \leqslant \varepsilon/1000$ can be imposed, when its effects will be completely negligible. Using the standard values this gives $2 \delta \alpha \leqslant 0.13°$, a condition readily satisfied, but with $\varepsilon = 10$ gamma/s.d. the figure is reduced to $2 \delta \alpha \leqslant 0.04°$, which is more difficult to attain.

ACCURACY OF LEVEL ADJUSTMENT

This question can be treated in a similar way by assuming $(\beta - \delta \beta)$ and $(\beta + \delta \beta)$ as the tilts in the two azimuths now assumed 180° apart. Then, with the same approximations as before

$$\delta Z - H \sin (\beta - \delta \beta) - (n H \sin \alpha) / 2 f = \varepsilon n$$
$$\delta Z + H \sin (\beta + \delta \beta) + (n' H \sin \alpha) / 2 f = \varepsilon n'$$

leading to

$$2 (\delta Z + H \sin \delta \beta) + (n' - n) F \sin \alpha = \varepsilon (n' + n)$$
$$2 H \sin \beta + (n' + n) F \sin \alpha = \varepsilon (n' - n)$$

which differ from (4) by an apparent increase in δZ by $H \sin \delta \beta$. If the condition is imposed that this shall be less than 1 gamma, then in the worst possible case (H = 35,000 gamma) $2 \delta \beta \leqslant 12$ sec. Since this is equal to half a division on the usual level, this is easy to achieve. Thus any change in the transverse level during a survey does not influence the mean reading provided that any change between the readings in the two azimuths corresponds to less than 12 sec. of arc, a change that is most improbable.

THE EXPERIMENTAL DETERMINATION OF α AND β

External adjustments can always be carried out so that the 180° rotation lies within the specified limits and it is easy to ensure that the transverse level, the level controlling the inclination of the knife edge, is adjusted in the two azimuths so that its readings agree to better than half a division. There remains the question whether β is less than the specified tilt when the level has its standard reading. Further, when the instrument has been set up with the compass accurately on the zero of its scale, the knife edge will, in general, make an angle α_0 with the magnetic meridian. Thus for any deliberate or accidental misorientation α, indicated by the compass, the real azimuth will be $(\alpha_0 + \alpha)$. Inserting this in the second of equations (5)

$$(n' - n) = 2 \cos \beta \{\varepsilon H \cos (\alpha + \alpha_0) \sin \beta + F \delta z \sin (\alpha + \alpha_0)\} / \{\varepsilon^2 \cos^2 \beta - F^2 \sin^2 (\alpha + \alpha_0)\}$$

The difference between the readings in the two azimuths is a few scale divisions and it cannot be determined with great accuracy. Thus it is sufficient to replace the cosines of all angles, even though they attain 10°, by unity. Even with this angle for $(\alpha + \alpha_0)$, $\{F^2 \sin^2 (\alpha + \alpha_0)\} / \varepsilon^2 = 0.024$ and this can be neglected in comparison with one. Hence, for all practical purposes

$$n' - n = \frac{2 H}{\varepsilon} \sin \beta + \frac{H \delta Z}{f \varepsilon^2} \sin (\alpha + \alpha_0)$$

or, if the angles are small and are expressed in degrees,

$$n' - n = \frac{\pi H}{90 \varepsilon} \beta + \frac{\pi H \delta Z}{180 f \varepsilon^2} (\alpha + \alpha_0)$$

Thus, for a fixed value of δZ, if the differences in readings are observed for various deliberate and known errors in α, the values should lie upon a straight line (Fig. 3). Further, independent of the value of δZ, which controls the slope of the line, all lines will pass through the point $\alpha = -\alpha_0$, $n' - n = \frac{\pi H}{90 \varepsilon} \beta$. By using an auxiliary magnet, or a Helmholtz Coil, and performing the experiment for different applied fields a set of lines intersecting at a point will be obtained. From the abscissa of the point the initial error α_0 in the orientation is obtained and, knowing the sensitivity and the horizontal field, the inclination β can be estimated from the ordinate.

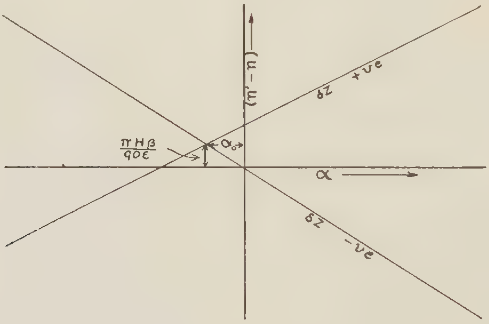

Fig. 3. Illustrating the theory of the orientation test.

There will be a certain field ($\delta Z = 0$) corresponding to the horizontal position of the magnetic axis for which the difference between the two readings will be a constant independent of the orientation. The mean reading corresponding to this condition can be obtained by plotting the slopes of the various lines against the mean reading. These should lie on a straight line which cuts the line of zero slope at the required reading. In most instruments the central reading of the scale is usually assumed to coincide with the horizontal position of the beam but the observed value will differ from this and, from knowledge of the optical constants, the difference can be converted into an angle. This angle will be made up of a number of parts. The magnetic axis may not coincide with the geometrical axis, the mirror on the magnet may be inclined at a small angle to the geometrical axis, and finally, when the levels are in their standard position the axis of the optical system may not be vertical. Of these, the first would appear the most important.

Practical examples of such experiments are shown in Figs. 4 and 5. In these diagrams the straight lines shown have been calculated from the observations by least square methods. In the first example the three lines, corresponding to the different mean readings given by the figures attached to them, intersect very closely in a point, the computed intersections being (0.50°, 0.18), (0.51°, 0.18) and (0.48°, 0.19) for the lines taken in pairs. Thus $\alpha_0 = - 0.50°$ and the mean ordinate gives $\beta = 32$ sec., the instrument having a scale value of 30 gamma/s.d. and H being 18000 gamma at the place of observation. The lower graph in the figure shows the change of slope with mean reading, zero slope corresponding to 23.7 s.d., 3.7 s.d. from the central reading of 20.0 s.d. This represents an angle of 0.16° made up of the three constituent angles indicated above. In the second case (Fig. 5) the intersection of the lines do not

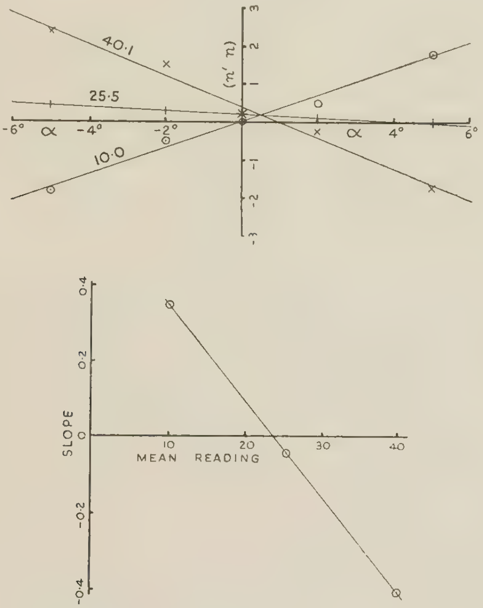

Fig. 4. The results of an orientation test.

agree so well but the mean corresponds to $\alpha_0 = 0.9°$ and $\beta = 44$ sec. The axis of the magnet is horizontal for a reading of 11.5 s.d., giving a composite angle of 0.37 degrees. It is obvious that, in both these cases the initial adjustments of the instrument are well within the required range of tolerance for the scale value and accuracy suggested, although for a scale value of 10 gamma/s.d., the value of α_0 for the second instrument is approaching the limit indicated earlier.

There remains the influence of the longitudinal level. Changes in this level result in tilts of the case only, without modifying the couples on the magnet. If during a series of observations, no change takes place and the reading of the level is always made constant, then the observations are made with a constant angle between the vertical and the axis of the optical system. A change in the relation between the direction defined by the level and the instrument case will lead to an extra tilt of the axis of the optical system and the effect will not be compensated by the mean of two readings. The magnitude of the effect will be the scale equivalent of the angular change in tilt and, since 0.1 s.d. corresponds to about 16 sec. of arc, it may be appreciable but not of great importance. Any variation of the level will modify the reading when the beam is horizontal but the method of determining this reading, as described above, would not be accurate enough to estimate very small changes. When the instrument is returned at suitable intervals to a base station to determine the diurnal variation, any observed change will in part be due to the diurnal variation and in part

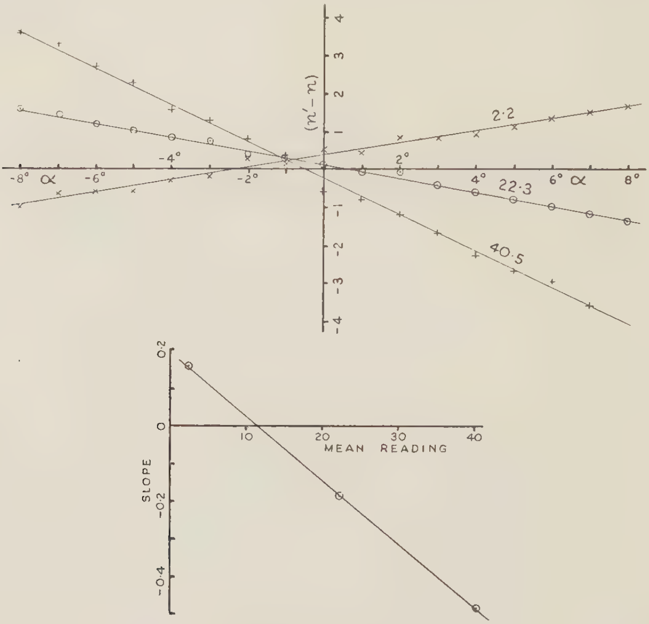

Fig. 5. Another example of the test.

due to any drift associated with the levels. If it is assumed that this drift occurs slowly and is linear with time, then its effect will be removed with the diurnal correction.

A MODIFIED INSTRUMENT

When using the vertical variometer in the field, there are two processes which must be carried out and which can occupy a large fraction of the time spent at any one station. These are the initial rough levelling so that the compass will swing freely for the accurate orientation of the head and the final levelling. The first of these is usually carried out by altering the position of the tripod legs, treading the feet into the ground and by altering the length of the legs themselves. The final levelling is made with the instrument footscrews and the difficulty arises because the turntable rotates relative to the levelling screws. Thus, unless the tripod has been set up with one leg accurately to the magnetic north or south, it is found impossible to manipulate the footscrews so that either one or other of the levels only is altered. As a general rule each footscrew or pair of footscrews when adjusted result in a change in the reading of both levels and the levelling becomes a series of successive approximations.

To avoid these defects and also to permit the orientation test to be carried out rapidly, a new tripod head has been designed and a prototype has been made. In this the whole of the head has been mounted on a ball and socket joint so that the axis of the system can be moved within a cone of about 15° semivertical angle. The initial rough levelling involves the unclamping of the ball joint by turning a clamping ring, the centering of a circular level on the turntable and a final clamping. In the orientation of the tripod head the levelling screws are carried round with the variometer turntable, the 180° stops etc., and the whole can be clamped in the correct position. Thus, the levelling screws always bear the same relation to the three holes which position the variometer on the turntable. The three feet of the levelling system form an equilateral right-angled triangle, the height at the right angle being fixed but the height at the other two angles being adjustable. Two independent tilts about two horizontal axes at right angles to each other are thus possible and the levels on the magnetometer case are parallel to these axes. The turntable can rotate independently of the main orientation between the 180° stops against which it can be clamped if considered necessary, but is normally held against them by a spring loaded lever. This lever clicks into position, giving a positive indication that the table is against the stop. Obviously on any instrument, the orientation test described above can be carried out by repeated use of the compass to obtain the known misorientations. In the present instrument, however, the member carrying the 180° stops can be rotated by itself on releasing a clamping screw and its position can be fixed on a scale with a central zero and graduations at ± 5° and ± 10° from the zero. In normal field operations the system is clamped against the zero mark when the levels on the variometer are correctly positioned in relation to the levelling screws.

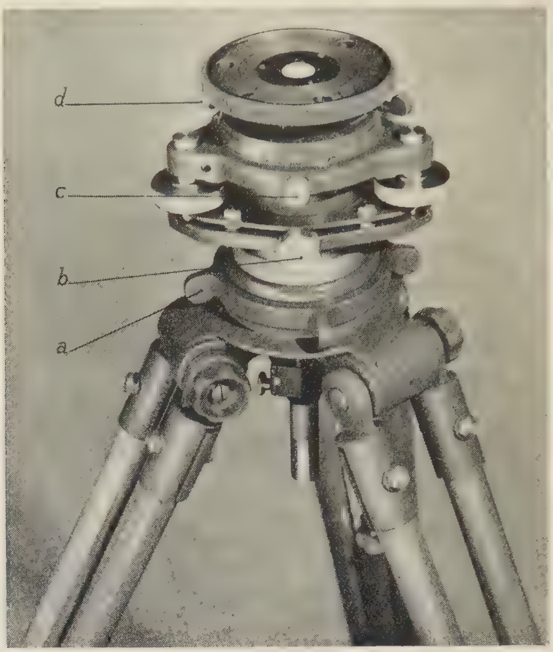

Fig. 6. The new tripod head showing scale for orientation test. a is the clamp for the ball socket, b clamps the whole head after orientation with the compass, c is the 180 degree clamp and d clamps the system during the orientation test.

ACKNOWLEDGE

I wish to place on record my appreciation of the discussions and assistance I have received from Mr. V. W. H. Towns and Mr. J. A. Armstrong of Messrs. Hilger and Watts Ltd. Without doubt it was their experience and knowledge of instrumental design that rendered possible the production of the prototype instrument described briefly here.

DISCUSSION

Mr. SCHLEUSENER: I remember once having an instrument in which the angle "α" was about 20°. The only explanation of this offered was that magnetisation of the blades had entirely changed in direction.

Mr. BRUCKSHAW: While not agreeing with your explanation I can offer no other. A component of magnetic moment parallel to the knife edge could have no such effect.

Mr. MYERS: I was pleased to hear about the change in position of the levelling screws but from experience with other surveying instruments I doubt whether levelling is quicker with the ball and socket joint.

Mr. BRUCKSHAW: With practise perhaps you would find that the ball and socket joint is the better.

Mr. FORBES: Surely the basic advantage of your method is to keep the height of the instrument constant?

Mr. BRUCKSHAW: That was not the basic idea, and it probably would not be true in any case because of the varying slopes of the ground.

Mr. FORBES: I was really thinking about the base station where it is always an advantage to have the height of the instrument constant.

Mr. BRUCKSHAW: That is true for the base station, but at other stations on sloping ground it might be necessary to alter the legs of the tripod as well. Levelling merely consists in keeping the attitude of the instrument case constant.

Mr. HABBERJAM: One can of course carry out the levelling with the same bubble reading in two directions at 180°.

Mr. BRUCKSHAW: There you are in fact making the axis of rotation vertical. That however is not a very satisfactory criterion for levelling since any grit between the instrument and the turntable will change the vertical axis in the instrument every time it is placed on the tripod (in this connection 10^{-3} cms is equivalent to 20″ of arc).

On the other hand the levels will always give the same attitude. You will keep a constant vertical axis (neglecting drift of the bubbles). However, as I indicated, errors due to the transverse tilt of the instrument will always be eliminated.

Mr. BRAEKKEN: I might mention that we have been using ball and socket joints for levelling purposes for many years. They are made in canvas-based plastic.

Mr. PEREBASKINE: Pour les lectures de précision, l'échauffement par le soleil, particulièrement l'échauffement des niveaux, a une très grande importance.

Mr. RICHARDS: Would this question of errors be simplified by the use of a null-reading instrument?

Mr. BRUCKSHAW: I think the errors would remain.

LAUFZEITANOMALIEN IM BEREICH EINER STÖRUNG *

VON

HANS ALBERT RÜHMKORF **

ABSTRACT

The measurement of well velocity data in the well of Scheibenhardt 1 has shown that it is possible to observe a well noticeable measurable increase of the travel time of seismic waves when approaching a disturbance. The tectonic event of the disturbance is combined in this case with a disorder (shattering) of the layers without subsequent cementation.

The significance of these anomalies for reflection seismics is discussed. When existing they will then overlap the diffraction, treated by Th. Krey.

In einer Veröffentlichung über „Ergebnisse seismischer Untersuchungen im Kohlenbergwerk Peissenberg" im Voralpengebiet hat Reich [1] durch Refraktionsmessungen nachgewiesen, dass im Bereich der Sulzer Querstörung, die die obere Bunte Molasse vom Promberger Sandstein trennt, eine Erhöhung der Fortpflanzungsgeschwindigkeit — also Laufzeitverkürzung — seismischer Wellen auftrat. Diese Feststellung erklärt Reich mit einer vielleicht durch Pressungsvorgänge und Verkittung der Spalten durch Kalkzement eingetretenen Verfestigung des Gebirges im Bereich der Störung. Der Verfasser weist auch bereits darauf hin, dass man ebenso gut im Bereich einer Störungszone, der andere mechanische Ursachen zu Grunde liegen, anstelle der Vergrösserung eine Verminderung der Fortpflanzungsgeschwindigkeit erwarten könnte.

Eine solche Geschwindigkeitsverminderung oder besser gesagt Laufzeiterhöhung wurde in der TB Scheibenhardt 1 nahe der pfälzisch-elsässichen Grenze bei einer seismischen Bohrlochmessung am 14. und 15.3.1952 tatsächlich festgestellt. Über diese Ergebnisse soll berichtet werden.

Die örtlichen und geologischen Verhältnisse sind folgende: Bild 1:

Die reflexionsseismischen Untersuchungen hatten auf Grund mehrerer Profile eine kräftige Störung in ihrer Streichrichtung und ihrem Verwurfbetrag sichergestellt. Sie wurde als „Östliche Hauptstörung" gekennzeichnet, die eine Hochscholle von der sogenannten Rheinscholle trennt.

Dies zeigt der Ausschnitt eines seismischen Profiles in Bild 2:

Die Tiefendarstellung war erfolgt auf Grund einer Geschwindigkeitskurve,

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* Presented at the Paris Meeting of the European Association of the Exploration Geophysicists, May 20/22, 1953.

** Seismos G.m.b.H., Hannover-Kirchrode.

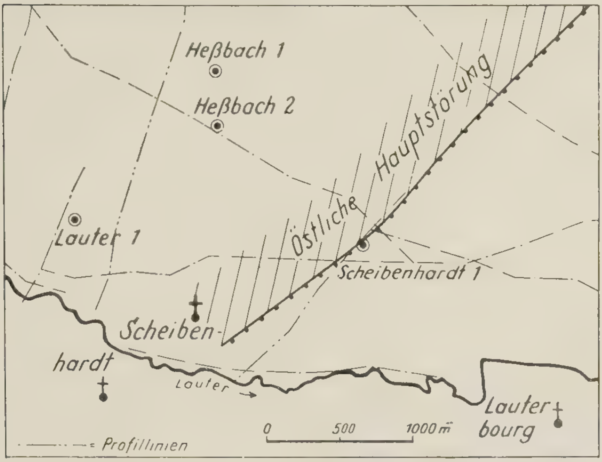


Fig. 1. Lageplan — Map.

die aus der Mittelung einer Reihe reflexionsseismischer Geschwindigkeitsmessungen nach der Methode der quadratischen Laufzeit gewonnen war. Auf der Seite der Hochscholle diente die ältere Bohrung Hessbach 2 zur stratigraphischen Deutung der Horizonte. Die erst später abgeteufte Bohrung Scheibenhardt 1 bestätigte dann die seismische Deutung in überzeugender Weise. Sie durchörterte überdies in einer Teufe von 1120 m die angegebene Störung und

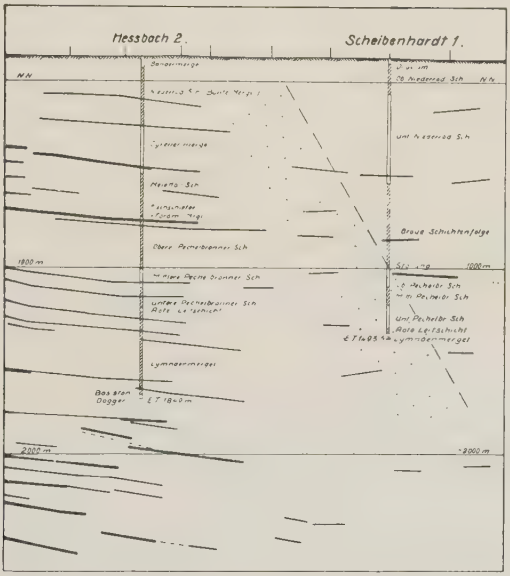


Fig. 2. Ausschnitt aus seismischem Profil — Part of seismic profile.

wurde nach Erreichen der Lymnäenmergel bei 1493 m eingestellt. Der einzige Unterschied ist, dass die seismische Auswertung von einer Störungszone spricht, während es sich nach der geologischen Auffassung um 2 engbenachbarte Störungen handeln könnte.

Für die seismische Bohrlochmessung, die zur Kontrolle der reflexionsseismischen Geschwindigkeitsmessungen diente, wurde die Anordnung der Schusslöcher nach folgenden Gesichtspunkten getroffen:

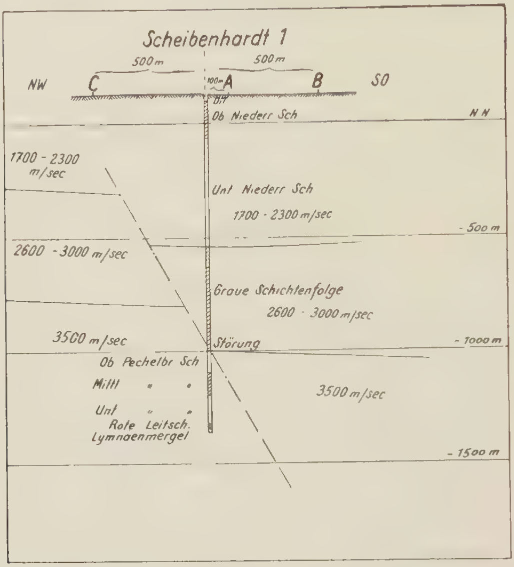
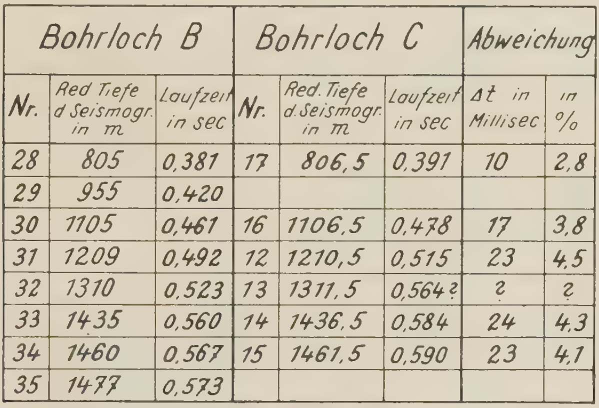


Fig. 3. Schussanordnung — Shooting arrangement.

Das Hauptschussloch A wurde in der üblichen Entfernung von 100 m von der Tiefbohrung auf der der Störung abgekehrten Seite senkrecht zu ihrer Streichrichtung angesetzt. Ein zweites Schussloch B in 500 m Entfernung nach derselben Richtung sollte zur Kontrolle und zur Feststellung eventueller Kabel- oder Rohrvorläufer in den Einsätzen aus Bohrloch A dienen. Nach dem vorher gezeigten seismischen Profil und nach den seismischen Geschwindigkeitsmessungen wurden etwa die in Bild 3 angegebenen Geschwindigkeitsstufen erwartet. Wenn es sich bei der angefahrenen Störung um eine glatte Bruchfläche handelte, die auf die Fortpflanzungsgeschwindigkeit der seismischen Wellen keinen Einfluss hatte, dann konnte man damit rechnen, dass die Laufzeiten von einem dritten Schussloch C in entgegengesetzt gleicher Entfernung wie B von einer gewissen Tiefe ab kürzer würden als von B aus, weil die Wellen auf ihrem Laufweg die Schichten höherer Geschwindigkeit auf der Seite der Hochscholle auch früher durchlaufen müssten als die Wellen von B aus auf der Seite der Rheinscholle.

Um eine möglichst einwandfreie Ablesung sicherzustellen, wurden ausser dem Schussmoment die Einsätze des Versenkseismographen auf zwei Spuren mit verschiedenen Verstärkungsgraden aufgenommen, ferner zur Kontrolle des Schussloches bezüglich möglicher Ermüdungserscheinungen der Einsatz eines weiteren Seismographen, der unmittelbar am Bohrlochmund der Tiefbohrung aufgestellt war.

Das Ergebnis der Messungen war eindeutig gegenteilig zur Erwartung. Dies zeigt die Gegenüberstellung in Bild 4.



Bohrloch B			Bohrloch C			Abweichung	
Nr.	Red Tiefe d Seismogr. in m	Laufzeit in sec	Nr.	Red. Tiefe d. Seismogr. in m	Laufzeit in sec	Δt in Millisec	in %
28	805	0,381	17	806,5	0,391	10	2,8
29	955	0,420					
30	1105	0,461	16	1106,5	0,478	17	3,8
31	1209	0,492	12	1210,5	0,515	23	4,5
32	1310	0,523	13	1311,5	0,564?	?	?
33	1435	0,560	14	1436,5	0,584	24	4,3
34	1460	0,567	15	1461,5	0,590	23	4,1
35	1477	0,573					

Fig. 4. Tabelle der Laufzeiten — Tables of traveltimes.

Es enthält zur besseren Übersicht lediglich die zu gleichen Tiefen des Versenkseismographen gemessenen Laufzeiten von den gleich weit entfernten Schusslöchern B und C. Dabei ist zu bemerken, dass die Einsätze von Schussloch B auf der Seite der Tiefscholle sehr scharf waren, während die von Schussloch C durchweg etwas weicher kamen und eher noch wenige Millisecunden später liegen könnten. Die Unterschiede sind auf jeden Fall so gross, dass sie weit aus dem Rahmen der Messgenauigkeit herausfallen. Wie man sieht, beginnt die Laufzeitabweichung bereits oberhalb der Störung und nimmt nach der Tiefe unterhalb der Störung auf einen Endwert zu.

Dies wird nochmals veranschaulicht durch die graphische Darstellung der vollständigen Auswertung in Bild 5:

Hier sind die auf senkrechten Weg reduzierten Laufzeiten t_z in Abhängigkeit von der Tiefe z des Seismographen unter Schussniveau aufgetragen. Die Parallelversetzung der Messwerte von Bohrloch B (die △) gegenüber Bohrloch A (die ×) ist für die hier zu betrachtenden Verhältnisse ohne Belang und stellt eine bekannte Erscheinung dar. Sie ist bedingt durch die erhöhten Brechungseinflüsse, die auftreten, wenn das Schussloch von der Bohrung weiter entfernt ist. Die Löcher B und C sind aber gleich weit, doch entgegengesetzt, von der Tiefbohrung entfernt und alle Werte von C aus, die Kreise, sind nach längeren Laufzeiten verschoben. Als Ursache für diese Feststellung darf wohl das Vorhandensein der Störung angesehen werden. Der mit der Tiefbohrung angefahrene Bruch stellt keine glatte Fläche, sondern eine breite, seismisch wirksame Zerrüttungszone dar, innerhalb deren der Gesamtverwurf zustande kommt, so dass in dieser Zerrüttungszone die Fortpflanzungsgeschwindigkeit vom Bohrloch C aus diese messbare Herabsetzung erfahren haben wird. Unterstützt wird diese Erklärung durch die Ergebnisse der reflexionsseismischen Untersuchungen, wie sie in Bild 2 gezeigt wurden. Der sonst gut ausgebildete seismische Leithorizont an der Grenze Fischschiefer/Pechelbronner Schichten blieb in diesem und mehreren anderen Profilen auf einer Strecke von ca. 500 m aus.

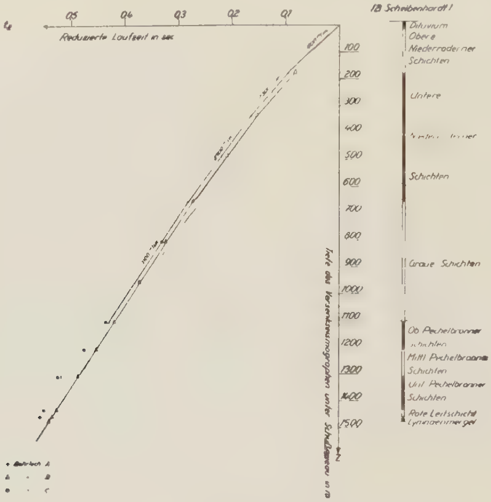


Fig. 5. Auswertekurve — Time-depth curve.

Auf ein weiteres Beispiel machte mich Th. Krey [2] aufmerksam. Er fand in der Bohrung Rehden 7 zwischen Weser und Ems bei Diepholz für den Hauterive eine Intervallgeschwindigkeit von 2540 m/sec, darunter für den Wealden, der vom Hauterive hier durch eine Störung getrennt ist, die wider Erwarten geringe Geschwindigkeit von nur 2300 m/sec. Sie kann ebenfalls auf eine Verzögerung der Laufzeiten infolge Zerrüttung zurückgeführt werden.

Nach diesen Ergebnissen ist es angebracht, dem Hinweis von Reich in seiner eingangs erwähnten Arbeit erhöhte Beachtung zu schenken, dass Geschwindigkeitsmessungen in Bohrlöchern, die im Bereich von Störungen abgeteuft wurden, mit einer gewissen Vorsicht zu benutzen sind. Man kann hinzufügen, dass die Anordnung der Schusslöcher bei der Durchführung solcher Messungen daher mit besonderer Sorgfalt auszuwählen ist, um — wie in diesem Falle — ein Mass für den möglichen Einfluss der Störung zu gewinnen.

Die Beobachtung der Laufzeiterhöhungen im Bereich einer Störung legt nun nahe, daran zu denken, dass diese Laufzeiterhöhungen sich auch bei reflexionsseismischen Aufnahmen bemerkbar machen können.

Krey [3] hat durch Anwendung der Kirchhoff-Sommerfeld'schen Beugungstheorie die Bedeutung der Beugung für die Seismik nachgewiesen. Er hat gezeigt und bewiesen, dass infolge der Beugung an einer Störung eine Verfälschung der Neigungen von Reflexionen und Überlappungen auftreten. Ein wesentliches Merkmal für den Beugungseinfluss ist dabei, dass die Grösse der Schwingungsamplituden nach der Störung abnimmt.

Wir wissen, dass die Amplitudenabnahme in der Feldpraxis jedoch nicht immer einwandfrei zu beobachten ist. Man muss also damit rechnen, dass die Beugung noch durch andere Effekte überlagert werden kann. Es erscheint möglich, dass dafür z.B. eine Zerrüttungszone im Bereich der Störung verantwortlich zu machen ist, in der eine Laufzeitanomalie seismisch wirksam wird.

Der Verfasser dankt der Deutschen Erdöl AG und ihren Konsorten, sowie der Seismos G.m.b.H. für die freundliche Erlaubnis zur Veröffentlichung dieser Arbeit. Er dankt ferner seinen Kollegen für anregende Diskussionen.

LITERATUR

[1] H. REICH, Erdöl und Kohle 4 (1951), S. 538.
[2] TH. KREY, mündliche Mitteilung.
[3] TH. KREY, Geophysics, XVII (1952), S. 843.

DISCUSSION

Herr KUNZ: Wir haben in Österreich vielfach bei Reflexionsmessungen an Verwerfungen die Beobachtung gemacht, dass die Spiegel der abgesunkenen Scholle an der Störung nach unten gekrümmt sind, obwohl geologisch eine Schleppung, also eine Krümmung nach oben erwartet wurde. Diese Erscheinung lässt sich durch Laufzeitverlängerung in der Störzone erklären. In diesem Sinne scheint mir die Beobachtung Herrn Rühmkorfs besonders wichtig.

Herr RÜHMKORF: Auch ich habe schon daran gedacht, dieses Phänomen mit der Laufzeitverlängerung in Zusammenhang zu bringen. Ohne aber dass dies durch eine Bohrung bestätigt ist, kann man so weitgehende Schlüsse nicht endgültig ziehen.

Herr WYROBEK: Considering that the well velocity survey was performed from 2 shot-holes 500 m. away on both sides of the well, are you satisfied that the time-differences observed (table 4) could be attributed entirely to the fact that shot-holes were situated on opposite sides of the fault?

Herr RÜHMKORF: Die Abweichungen sind zu gross, als dass man sie allein auf Fehler in der Messung zurückführen kann.

Herr BADING: Herr Richard hat im Dezember 1952 in Hannover einen Vortrag gehalten unter dem Titel „Reflexions multiples obliques". In einer Darstellung wurde gezeigt, wie durch eine steile Verwerfungsfläche Reflexionen verursacht werden. Doch auch vor und hinter der Verwerfungsfläche waren Spiegel gezeichnet, die parallel zur Verwerfung lagen und die, wenn ich recht verstanden habe, ihren Ursprung in Elastizitätsunstetigkeitsflächen parallel vor und hinter der Verwerfung haben sollten. Bei Messungen im Ruhrkarbon habe ich ebenfalls steile Reflektionen von ca. mit 60° einfallenden Bruchflächen erhalten, ausserdem auch Spiegel von Flächen, die parallel vor und hinter der Bruchfläche lagen. Wie im Beispiel von Herrn Richard müssen diese Spiegel durch Flächen verursacht sein, die parallel vor und hinter der Bruchfläche liegen und Elastizitätsunstetigkeiten darstellen.

AN ATTEMPT TO INTERPRET THE GRAVIMETRIC MAP OF THE NORTHERN PART OF THE MOROCCAN BASIN OF GHARB. MAPS OF RESIDUAL ANOMALY AND FIRST DERIVATIVE*

BY

SOCIETE CHERIFIENNE DES PETROLES
AND C. AYNARD**

ABSTRACT

The main features of the gravimetric map of the Gharb can be related to the shape of the basement, covered by cretaceous and miocene layers, with a total maximum thickness of 13.000 feet. For the interpretation of local features, in the northern part of the basin, first a regional anomaly has been drawn, then the map of the first derivative has been established.

Both maps are compared with geological maps and seismic and electrical surveys.

The results are the following:

As for method, the advantages and limitations of both processes are outlined.

As for geological interpretation, it is suggested that most of the local features of the gravimetric map are due to the preriffan tectonics.

The gravimetric map of the Gharb has the shape of a trough. (Fig. 2; Bouguer d = 2,2).The paleozoic outcrops of the Moroccan Meseta in the south are outlined by isogamm O; then the Bouguer Anomaly falls off towards the axis of the trough, which is about East-West in azimuth (Fig. 1). The minimum values (-120 milligals) are found in the lower valley of Querrha; then the anomaly steadily increases towards the North and North-West.

What can be the general interpretation of this gravity feature? The answer is comparatively simple for the Southern flank; owing to many deep wells of the Societe Cherifienne des Petroles, we see that the sedimentary basin (made of Miocene and of the mainly Cretaceous Preriffan unit), which is more than 3.000 meters thick North of Petitjean, thins out towards the Paleozoic outcrops.

However the importance of the variation is a hint that a very deep effect, due to the absence of isostatic compensation, is superimposed to the effect of the low density sedimentary basin. Yet this effect, of a great theoretical interest, is beyond the scope of this paper.

The Northern part is not nearly as simple to interpret since no equivalent of the Paleozoic outcrops of the South is reached and besides no deep well has reached the basement in that area.

Therefore the question can be raised of whether the increase of the anomaly is due mainly to a general uplift of the basement, or to some deeper effect.

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* Presented at the Paris Meeting of the European Association of Exploration Geophysicists, May 20/22, 1953.

** Compagnie Générale de Géophysique, Paris.

Geophysical methods, other than gravity surveys, allow to give a provisional answer to the question.

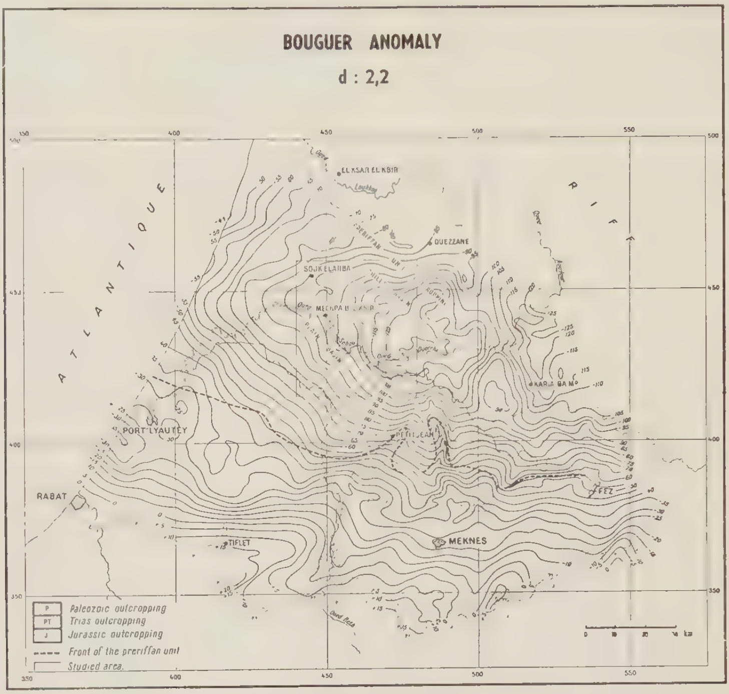


Fig. 1.

The seismic reflection survey shows almost horizontal mirrors, in the main gravimetric "low", down to 4.000 meters and more.

Similar markers are observed only down to 2.500 and 3.000 more to the North. This will be shown later on a recent profile.

The results of electrical soundings method (with long output lines) are in complete agreement with the seismic survey, including the order of magnitude for the depths.

Therefore the main features of the gravimetric map can be interpreted as the shape of the basement, with comparatively little distortion by deeper effects. But of course many interpretation problems of detail are still to be solved, especially in the Souk El Arba-Mechra Bel Ksiri area, in connection with the tectonical unit known as the Preriffan overthrust.

This unit has slipped over the North Eastern half of the Basin, during the lower Miocene; tectonics are of the "flowage" type; it is very strongly folded in the detail.

One can suppose either that the Preriffan unit is molded over some accidents of the basement or that the folding is due to a salt dome type tectonics without any relation to the shape of the basement.

We do not know which of these 2 mechanisms is the most important.

As a method of investigation, one can study separately the shape of the basement and the structure of the Preriffan unit and look for analogies afterwards. We have reanalysed the gravimetric map with this object in view.

First one has to point out that in the Souk El Arba area the basement has an average depth of more than 3.000 meters, probably even 4.000 meters, while the Preriffan unit is either outcropping (in the "Hills Basin") or buried under 1.500 meters of Miocene (or so), in the "Plains Basin". Therefore gravimetric anomalies related to the structure of the basement and those related to the salt dome type tectonics will have a very different radius of curvature.

Then we have tried to eliminate the effect of the general shape of the basement, first by drawing a regional anomaly and second by etablishing a first derivative map.

a) *Regional anomaly*

It has been drawn by graphically smoothing 7 profiles.

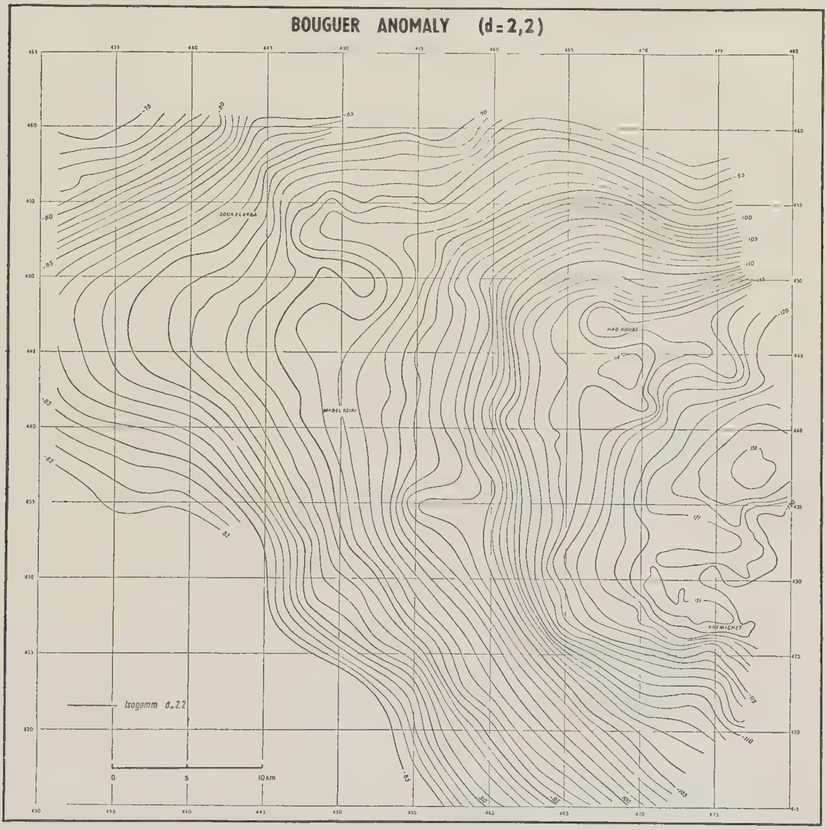


Fig. 2.

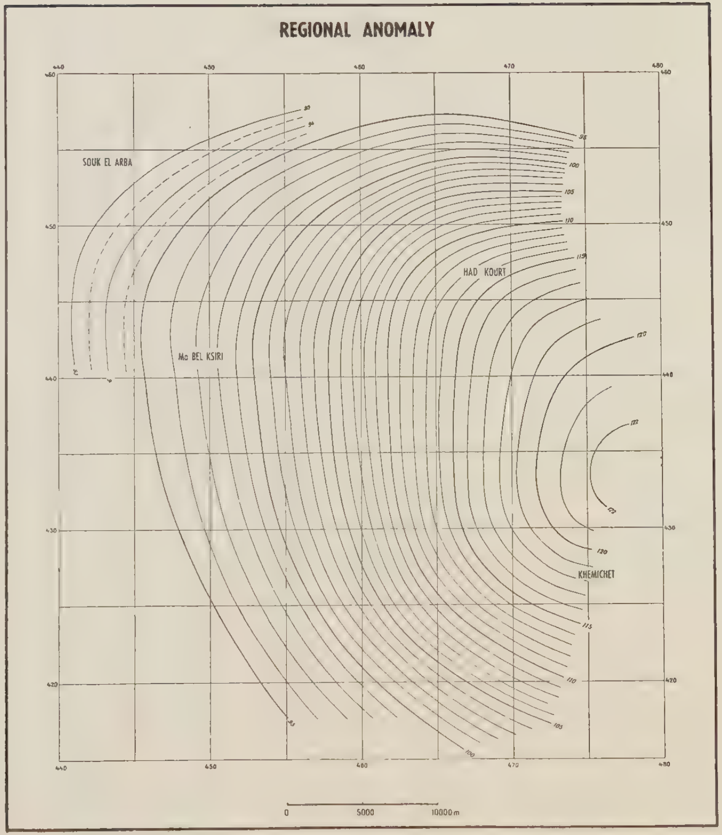

REGIONAL ANOMALY
SOUK EL ARBA
HAD KOURT
Ma BEL KSIRI
KHEMICHET
95
100
105
110
115
120
122
125
0
5000
10000 m

Fig. 3.

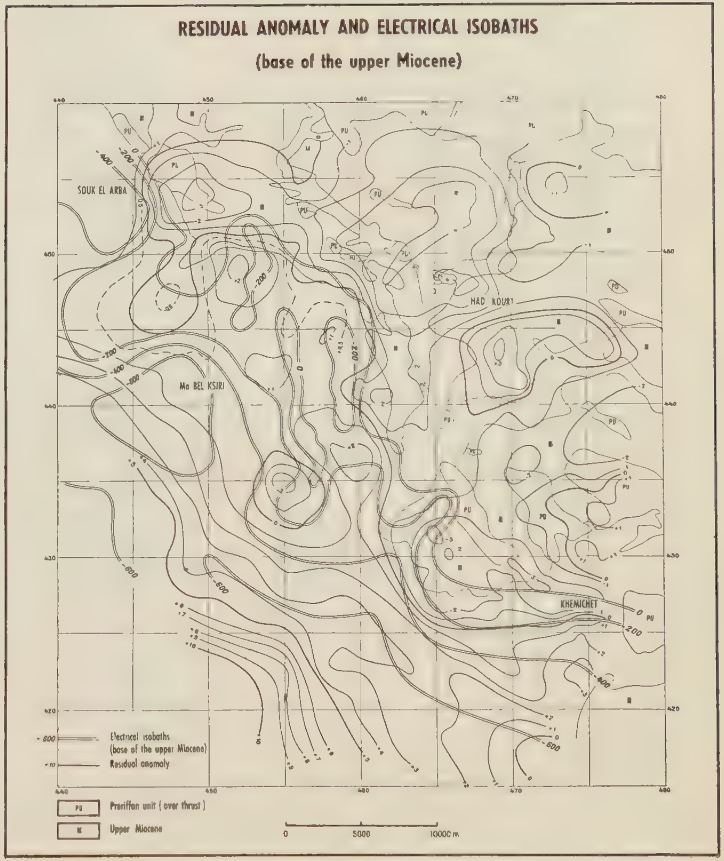

RESIDUAL ANOMALY AND ELECTRICAL ISOBATHS
(base of the upper Miocene)
SOUK EL ARBA
HAD KOURT
Ma BEL KSIRI
KHEMICHET
PU
-200
-400
-600
0
200
- 600
Electrical isobaths
(base of the upper Miocene)
+10
Residual anomaly
PU
Preriffan unit (over thrust)
M
Upper Miocene
0
5000
10000 m

Fig. 4.

Bouguer anomaly is shown on Fig. 2, regional anomaly on Fig. 3, and the residual anomaly on Fig. 4.

We shall compare this residual anomaly with whatever is known of the structure of the Preriffan unit.

Therefore on Fig. 4 are shown:

1° — a simplified geological map;

2° — a map established by electrical soundings of the contact between the Upper Miocene (sandy) and the lower Miocene (clay). The contact is roughly parallel to the top of the Preriffian unit; we shall see an instance of this later on a seismic profile.

This map definitely links the tectonics of the Preriffan unit in the "Plains Basin" to the outcrops. Geologically the boundary between the "Plains Basin" and the "Hills Basin" is not well defined, since it is partly hidden by recent deposits.

A striking similarity between the maps of residual anomaly and the said electrical map can be observed.

Isogram O. follows closely electrical isobaths 0 - 100 - 200, showing the same typical Z design, for the boundary of the "Plains basin".

In other words, if one admit that the Miocene and Preriffan (cretaceous) clays are a single low-density body, that means that the sandy upper Miocene is responsible for the *positive* anomalies of the "Plains Basin", while on the other hand the tops of the Miocene Structures show up on the gravimetric residual map as *negative* anomalies (see especially the Miocene structure of Njara Doukkala, North of Mechra Bel Ksiri, where the agreement is very good).

The excess of density of the upper Miocene should be about 0,2 in order to account for these anomalies.

On the outcrops of the Preriffan unit (Hills Basin), some negative anomalies should be linked to Triasic salt outcrops; positive anomalies are related to Oligocene sandstones. But we shall not deal with these in the present paper.

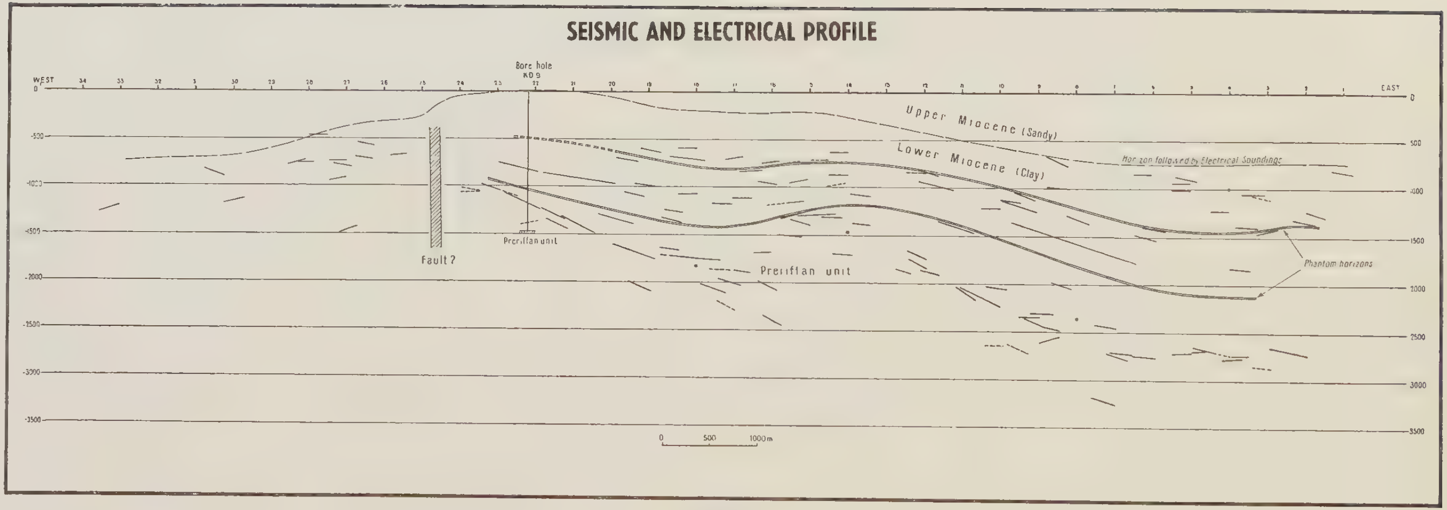
In support of the view that the marker in the upper Miocene is parallel to the top of the Preriffan unit, a seismic cross section (geological congress of Alger August 1952) is shown. (Fig. 5).

b) *First derivative*

A map of the first derivative has been drawn (Fig. 6).

A close similarity with the residual anomaly map can be observed; the boundary between the "Hills Basin" and the "Plains Basin" is shown, in good agreement with the electrical map.

The 'Hills Basin" shows up as an area with complicated strong negative anomalies (-15 and less), while the "Plains Basin" is less disturbed without sizable negative anomalies (except on the North West as explained later).



SEISMIC AND ELECTRICAL PROFILE

Fig. 5.

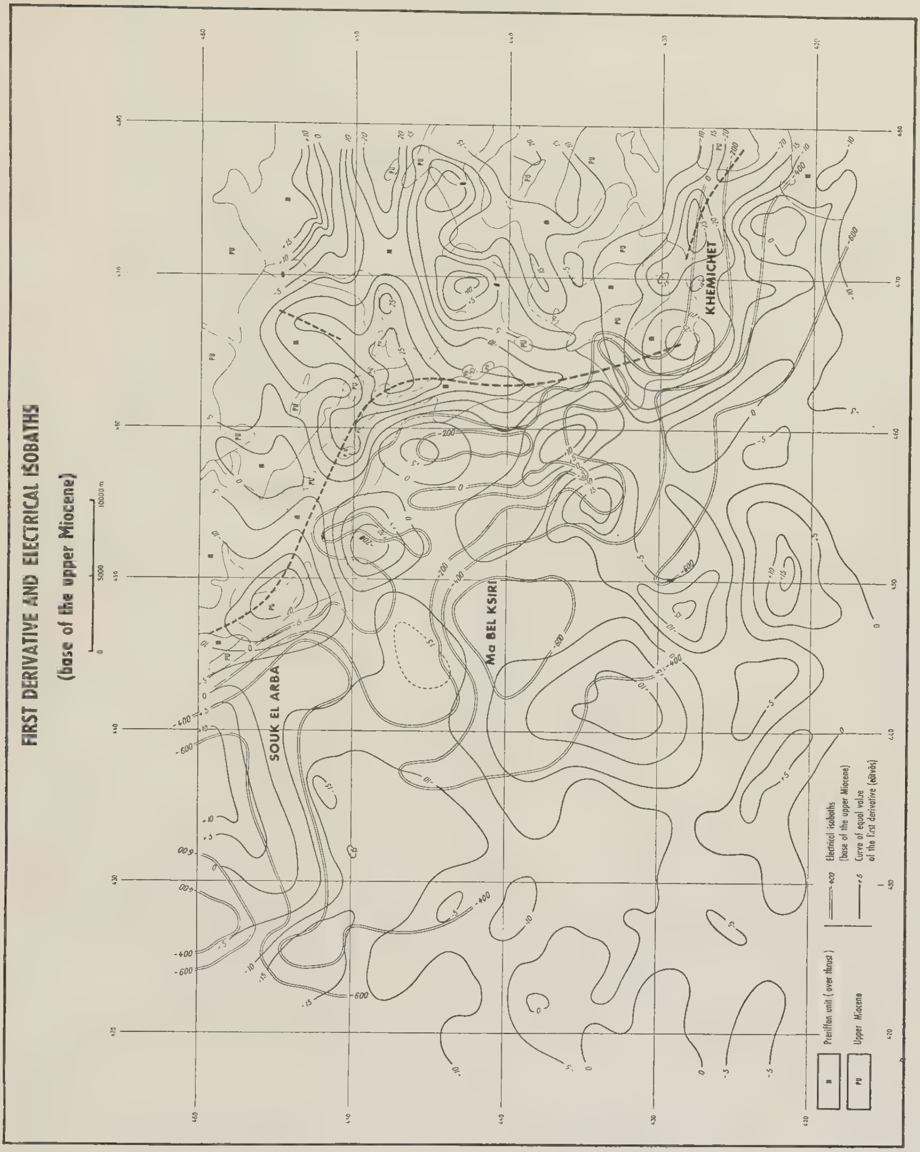

FIRST DERIVATIVE AND ELECTRICAL ISOBATHS
(base of the upper Miocene)
0
5000
10000 m
SOUK EL ARBA
Ma BEL KSIRI
KHEMICHET
PU
Preriffon unit (over thrust)
Upper Miocene
Electrical isobaths
(base of the upper Miocene)
Curve of equal value
of the first derivative (eötvös)

Fig. 6.

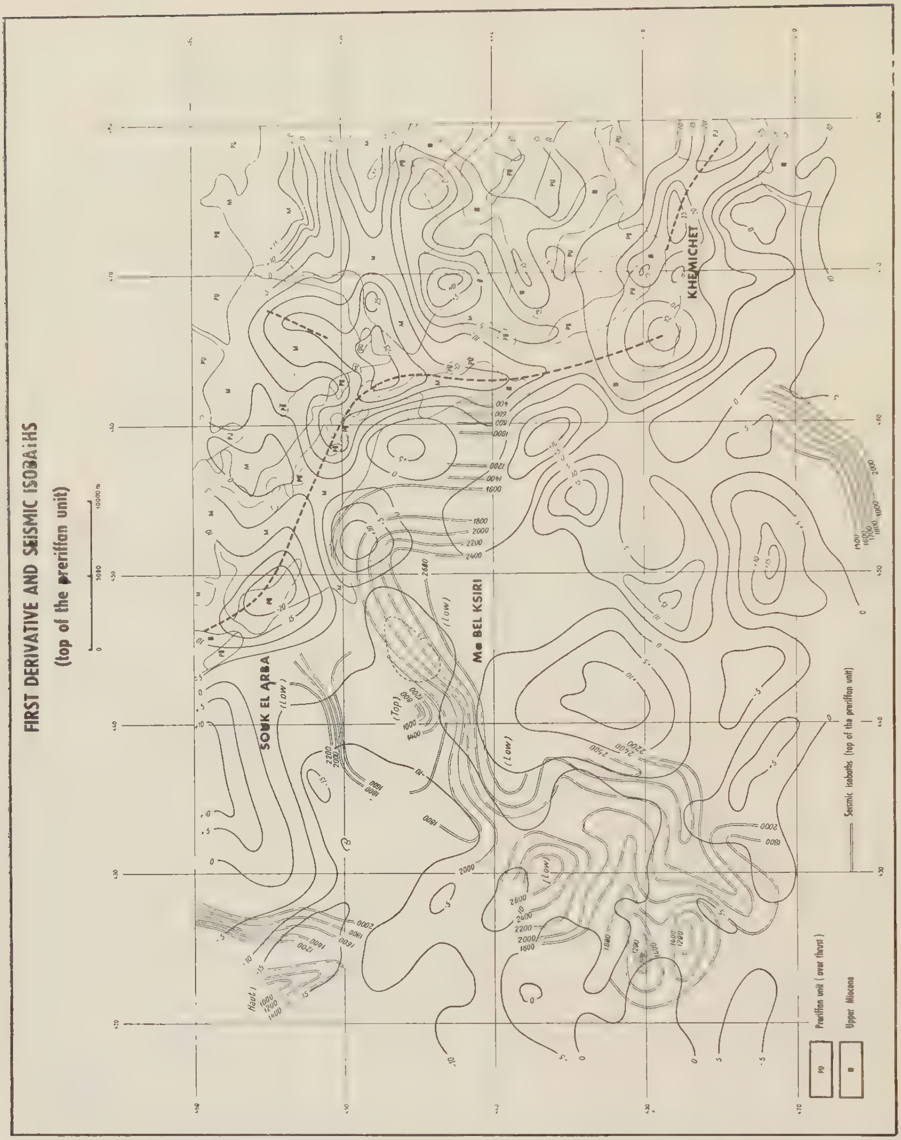

FIRST DERIVATIVE AND SEISMIC ISOBATHS
(top of the prerifian unit)
0
5000
10000 m
SOUK EL ARBA
(Low)
Ma BEL KSIRI
(Low)
(Top)
KHEMICHET
Prerifian unit (over thrust)
Upper Miocene
Seismic isobaths (top of the prerifian unit)

Fig. 7.

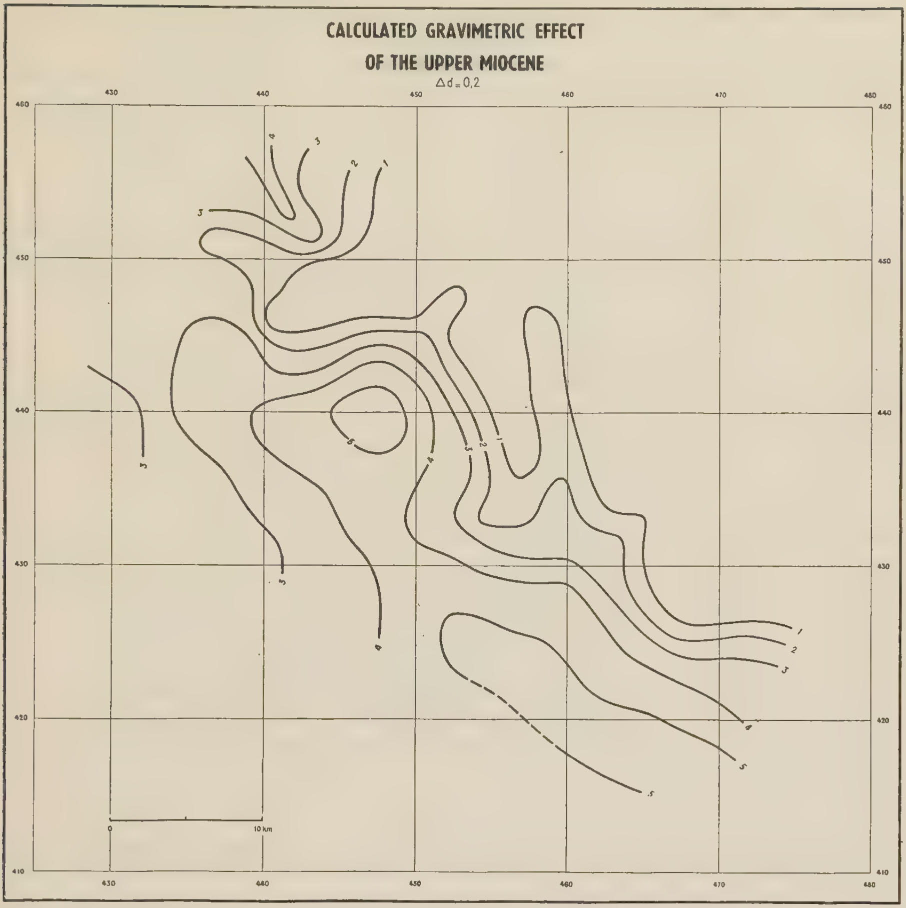


Fig. 8.

Thus, the first derivative method appears to be able to define major structural features, and this with a strictly objective, non hypothetical, process.

On the other hand one can notice that the agreement with the electrical map is less perfect than in the case of the residual anomaly map, for detail features (especially the Miocene structure of Njara Doukkala).

The first derivative map has been established on a wider area than the residual anomaly, so that a comparison with the seismic map of the top of the Preriffian unit is possible (Fig. 7).

A good agreement is observed just as for the electrical map, with *positive* gravimetric anomalies corresponding again with seismic synclines due to the effect of the sands of the upper Miocene.

The only strong negative anomaly (— 15), on the North-Western edge of the surveyed area, checks with a pronounced high of the Preriffan unit, with a probable occurence of salt.

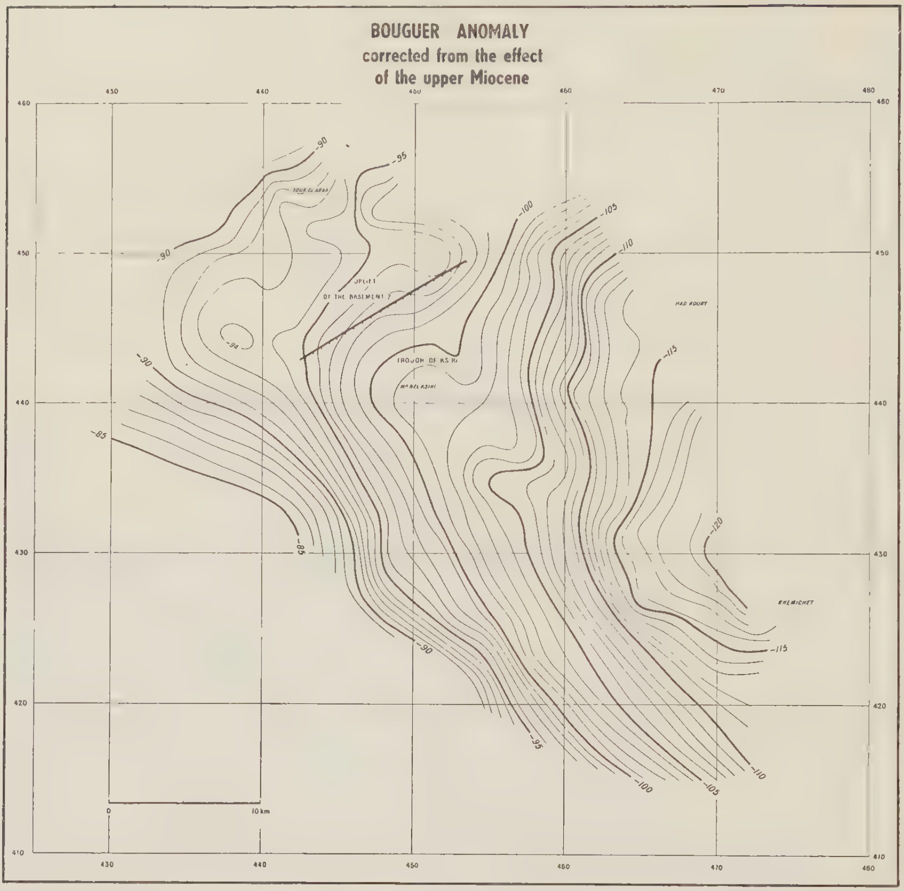


Fig. 9.

Some narrow seismic structures fail to show up on the gravimetric map, but it should be noted that the density of gravimetric stations is only 0,7 per km².

As a conclusion, the working hypothesis that the Bouguer map is shaped mainly, in the detail, by the Preriffan and Miocene tectonics, is fairly well confirmed. Therefore we have tried to eliminate these effects, which we have ascribed to an excess of density of 0,2 for the upper Miocene.

This calculated effect is shown on Fig. 8. Then it has been substracted from the Bouguer.

The map of the corrected anomaly obtained then (Fig. 9) is actually simpler than the Bouguer map, and new features appear which are still to be interpreted. One is the high gradient North of Mechra Bel Ksiri with an unexpected North East — South West direction.

If we plot against the recent seismic profile the corresponding Bouguer anomaly and corrected anomaly, we see that the agreement is much better with

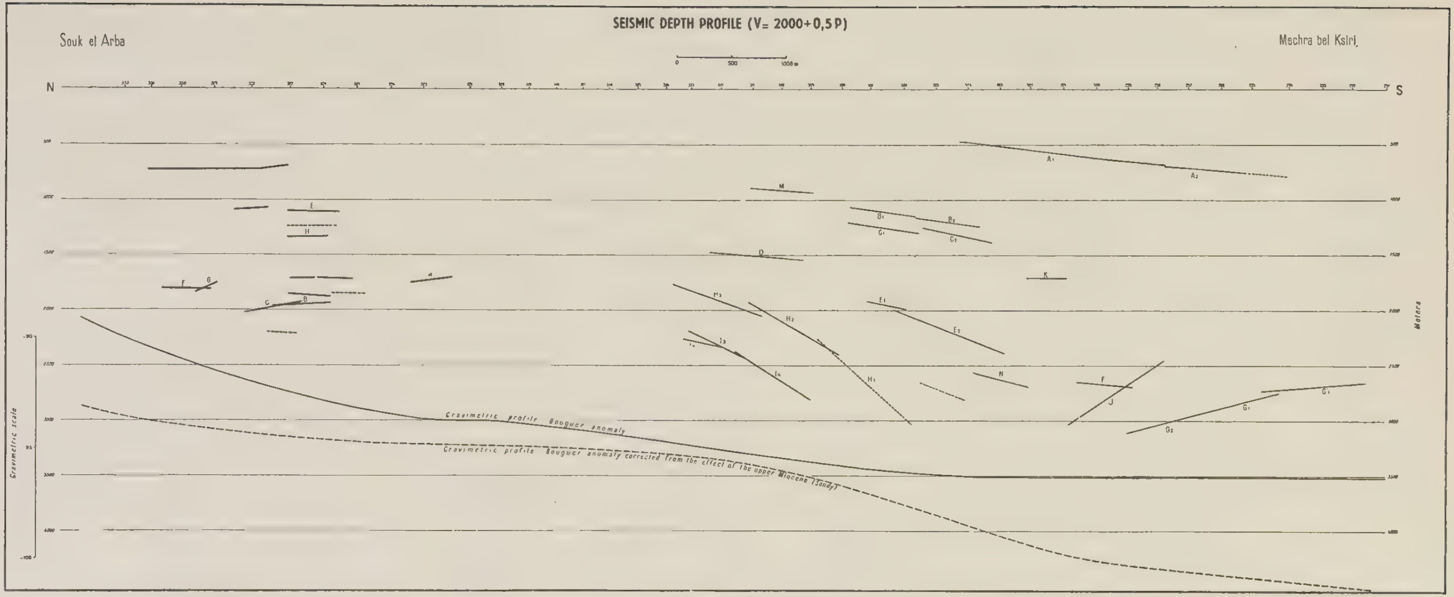

SEISMIC DEPTH PROFILE (V= 2000+0,5 P)
Souk el Arba
Mechra bel Ksiri,
0
500
1000 m
N
S
Meters
Gravimetric scale
-90
95
-100
500
1000
1500
2000
2500
3000
3500
4000
A₁
A₂
M
E
H
B₁
B₂
C₁
C₂
D
F
G
C
B
K
H₃
H₂
H₁
E₁
E₂
I₃
I₄
N
F
J
G₁
G₂
Gravimetric profile Bouguer anomaly
Gravimetric profile Bouguer anomaly corrected from the effect of the upper Miocene (Sandy)

Fig. 10.

the corrected anomaly (Fig. 10); the high gradient of the corrected map checks fairly well with an uplift in the basement suggested by the seismic profile.

CONCLUSION

Although confirmations by seismic prospecting and by drilling are still scarce, we can assume that the interpretation based on the first derivative is successful not only for local structures, but also for defining the major features of a sedimentary basin (boundary of the "Plains Basin" in the present case).

This method is strictly objective and eliminates every personal factor. However, it should be compared with a graphical residual anomaly; and finally all other geophysical data have to be used. In the present case the gravimetric effect of the upper Miocene is well defined by the electrical survey and the elimination of this effect from the Bouguer map is another step towards the knowledge of the general shape of the basement in the Northern Gharb.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

174. *Increase in Geophysics.*
R. F. Carlson, Oil & Gas J., Vol. 51, No. 3, pp. 68, May 26, 1952.

Addressing the first Annual Meeting of the Permian Basin Geophysical Society, H. L. Swords of the Union Oil Co., California, said that geophysical activity in the U.S. had increased from 210 seismic and 50 gravimeter crews in 1942 to 600 seismic and 80 gravimeter crews at the present time.

175. *Well Logging Instrumentation.*
A. A. Stripling, World Petroleum, Vol. 23, No. 6, June, 1952.

Brief descriptions of the methods and instruments used in obtaining the following well logs:—cutting-sample log, electric log, radioactivity log, caliper log, temperature log, dipmeter log, drilling-time log, chemical mud-analysis log, magnetic susceptibility log, total magnetic field log, acoustic log, and dielectric constant log.

176. *Occurrence of Oil.*
Oil & Gas J., Vol. 51, No. 5, p. 55, June 9, 1952.
(Digest only of paper read at the Annual Gulf Coast meeting of the S.E.G., at Houston on May 29-30).

M. King Hubbert, of the Shell Oil Co., Houston, said that the anticline theory of oil accumulation is but a special case and that oil and gas may occur in structural terraces, noses, monoclines, and other enclosed structures devoid of lithologic barriers to undip migration. Oil and gas in a dispersed state tends to migrate to lower levels.

177. *Today's Promise of Geophysics.*
P. C. Ingalls Oil & Gas J., Vol. 51, No. 5, p. 123, June 9, 1952.

Oil fields are being found by working old records, many others could be found with more intensive use. More records should be exhumed and reworked with the advantages not available to the first few men who studied them.

178. *Geophysical Surge.*
Oil & Gas Jrnl., Vol. 51, No. 12, p. 191, July 28, 1952.

Investigations in the Williston Basin are costing about £ 700,000 a month. There are 118 seismic, gravimeter, and magnetometer parties now working in the basin. The approximate cost involved in running a seismic party in the field is £ 7,000.

179. *Application of Geophysical Technique to Finding More Flank Production on Piercement-Type Salt Domes.*
P. Weaver, Oil & Gas Jrnl., Vol. 51, No. 7, pp. 80-94, June 23, 1952.

A discussion of the problems which may arise when an attempt is made to pinpoint locations on the flanks of piercement domes. The shape of the salt mass is required—it may flare with depth, or may have an overhang. Gravity work will give an idea of the volume, but not of accurate configuration.

At present, the most accurate way of determining the shape of the salt mass is by the use of a deep well drilled either down into the salt, near the centre of the dome, or the use of several wells around the flank. In either case the method involves a number of observations with shots on the surface and detectors at different depths in the well.

The problems of mapping flank beds are also discussed.

180. *Oil Finding.*
F. A. Morgan, Bull. Amer. Ass. Petrol. Geol., Vol. 36, No. 7, pp. 1297-1304, July, 1952. (Presidential address, 37th Annual Meeting at Los Angeles, March, 1952).

Mr. Morgan decries the pessimists who constantly claim that the U.S. is running out of oil reserves. He stresses the need for more extensive geological survey drilling by geologists, the geologists' selling of the idea to management, and the geologists having access to as much of this type of work as is considered necessary for integration with geophysical work and other exploration operations.

181. *Our Inexhaustible Resources.*
E. Holman, Bull. Amer. Ass. Petrol. Geol., Vol. 36, No. 7, pp. 1323-29, July, 1952.

This paper discusses the quantities of natural resources available for human use. They are too often under-estimated.

182. *Geophysical Exploration in the San Juan Basin.*
N. Clayton, Geophysics, Vol. 17, No. 4, pp. 900-906, Oct., 1952.

Geophysical surveying in the San Juan Basin involves a number of problems peculiar to the area. Magnetometer and gravimeter surveys are complicated by topography and the presence of Tertiary intrusives. Scarcity of water is a major problem for seismic crews. Some arrangements must be made for housing crew employees. Velocity and subsurface control are extremely limited.

183. *Correlation and some Geological Interpretation of the Seismic and Gravimetric Surveys in Cukurova.* (In Turkish & English).
S. Yüngül, Türkiye Jeoloje Kurumu Bülteni, Vol. 3, No. 2, pp. 27-45, 1952.

In Cukurova, Turkey, gravity and seismic surveys resulted in bad correlation. Each method indicated highs where the other method disagreed. More recently, the area has been re-surveyed and a satisfactory correlation between the two methods has been found.

184. *History and Status of Petroleum Exploration in Uruguay.*
Ferrer, Arturo, Serra, Nicolas, Holmer, Ralph, & E. F. Taylor, Bull. Amer. Ass. Petrol. Geol., Vol. 36, No. 4, pp. 677-687, 1952.

Uruguayan exploration is being conducted by government agencies in co-operation with North American specialists. Geological studies were followed by geophysical surveys, using gravity, magnetic, and electrical resistivity methods, of the basalt-covered basin in the northwestern section. Information on structural trends below the the basalt is sought.

185. *Safe Operations — A Challenge to the Geophysical Industry.*
B. W. Sorge, Petroleum Engineer, Vol. 24, No. 10, pp. B-107-112, Sept., 1952.

Lack of elementary safety precautions caused at least 5 deaths in U.S. geophysical activities during 1951. Statistics prove that a well-planned safety programme is well worth while. The basic requirements for such a programme are outlined and discussed.

186. *Exploration at Peak.*
Oil & Gas J., Vol. 51, No. 21, p. 149, Sept. 29, 1952.

During August, 1952, in Western Canada there were 183 geophysical parties active: 164 seismic, 15 gravity and 4 magnetic. Of these, Alberta had 118 seismic and 9 gravity; Saskatchewan had 39 seismic, 5 gravity and 2 magnetic; British Columbia had 4 seismic and 1 magnetic; Manitoba had 3 seismic and 1 gravity; the Northwest Territories had 1 airborne magnetometer party.

187. *Exploration in Nova Scotia.*

R. A. Pohly, Oil & Gas J., Vol. 51, No. 22, pp. 118-127, Oct. 6, 1952.

Seismograph Service Corp. recently carried out gravity and magnetic surveys of the south side of Antigonish harbour, in Nova Scotia. A brief report on the general geology shows that the Pennsylvanian and Mississippian Sections of the Carboniferous offer potentialities for oil or gas production. A surface geology map of the Antigonish area is presented.

Maps of residual gravity and vertical magnetic anomalies are also given. Since a definite regional gradient was not established, the gravity anomalies might be considerably altered by a more extensive survey. The significance of intense magnetic maxima is discussed, and it is concluded that the anomalies would appear highly favourable for the accumulation of hydrocarbons.

188. *Role of Electronics in Geophysical Instrumentation.*

F. F. Segesman, Oil & Gas J., Vol. 51, No. 24, p. 152, Oct. 20, 1952.

For radioactivity surveying, the scintillometer is a hundred times as sensitive as the Geiger counter, and with the former, cosmic ray interference is cut down by the same proportion. For surface prospecting, instruments need to be rugged, portable, weather-proof, and temperature controlled. A method for measuring sub-surface conductivity is described. The Shoran method of radio prospecting is limited and will probably be replaced by the Decca, Raydist, or Lorac methods which have a greater range.

The techniques of borehole measurements of resistivity, spontaneous potentials, radioactivity, seismic velocity, temperature gradient, hole size, inclination and direction, magnetic susceptibility, and earth dip, are discussed.

189. *There's Still Shallow Oil in N.E. Oklahoma.*

Dr. L. M. Wright, World Oil, Vol. 135, No. 3, pp. 114-120, August, 1952.

Consistent strikes along the Seminole Uplift of N.E. Oklahoma show that there is still a lot of shallow oil to be produced. Formations are mostly of the stratigraphic type and are difficult to find. However, the shallow depths of less than 3,000 feet are the reward. The stratigraphic formations encountered may be classed as follows:

(a) Stratigraphic pinchouts resulting from the deposition of sediments in the valleys of the pre-Cambrian topography.
(b) Stratigraphic pinchouts resulting from the on-lap deposits of a transgressing sea.
(c) Stratigraphic traps resulting from faulting.
(d) Channel or lensing sands as a result of irregular deposition in shallow water.
(e) Anticlinal traps formed by the differential compaction of the beds around the pre-Cambrian highs.

Some suggestions for pursuing these formations are made, and the geological history of the area is described.

190. *Exploration Record.*

Oil & Gas J., Vol. 51, No. 15, p. 77, Aug. 18, 1952.

During July, 175 geophysical parties were active in Western Canada. This represents 32% more than the corresponding figure last July. The 175 crews comprise 157 seismic, 15 gravity and 3 magnetometer. Alberta was most active with 122 crews in the field. Saskatchewan had 41 crews operating. Other activity was in British Colombia, Manitoba and the Northwest Territories.

191. *Low Cost Structure-drill Program Increases Mene Grande Wildcat Success Record.*
N. V. Middlesworth, World Petroleum, Vol. 23, No. 10, pp. 64-68, Sept. 1952.

Mene Grande Oil Co. have, since 1939 accounted for the drilling and electric logging of nearly 4,800,000 feet of hole, up till May, 1952. This structure drill programme, operated in close co-operation with a reflection-seismograph shooting programme, has been one of the most vital factors in the exploration and development of the Greater Oficina area in Eastern Venezuela.

The policy has been to cover an area first with reflection seismograph and then check with structure drill the various fault features indicated by two sets of interpretations, one furnished locally by party interpreters, and a second by Gulf Research and Development Corp. The interpretations occasionally show considerable disagreement on strike and dip of the all-important faults. The structure drill work, which more precisely locates the faults, furnishes unquestionable information on the dip of the faults, and occasionally locates faults not delineated by seismograph.

192. *A Seismologist's View of Western Canada.*
F. B. Leedy, World Petroleum, Vol. 23, No. 10, pp. 90-93, September, 1952.

North of Alberta some 250,000 square miles of Northwest Territory will eventually be explored by geophysical methods. A glacial drift layer, of extremely variable thickness, creates problems for both geologists and geophysicists. The geologist is mostly limited to information obtained from well or shothole logs, whereas the geophysicist is almost invariably confronted with the problem of making satisfactory near-surface corrections.

The seasonal aspect of the operational problem is troublesome both to the oil companies and to the geophysical contractors. Intense cold in Winter and severe mud conditions in Summer are to be contended with. Specialized equipment is used so as to minimize the necessity of a seasonal migration from one type of area to another.

Some reef characteristics are given, since Canada's most prolific oil source is in Devonian reefs near Edmonton.

SEISMIC — GENERAL

193. *Seismic Exploration of the Denver-Julesburg Basin.*
B. F. Rummerfield, Geophysics, Vol. 17, No. 2, pp. 334-343, April, 1952.

Recent developments in N.E. Colorado and S.W. Nebraska have resulted in a marked increase in seismic activity within the Denver-Julesburg basin.

The low relief of many of the subsurface structures, coupled with the extraneous effects of weathered zone, elevation changes, surface deposits and velocity variations taxes the resolving power of the seismic method and the interpretive ability of the geophysicist.

194. *Seismic Refraction Experiments in the Pacific.*
Dr. T. F. Gaskell & J. C. Swallow, Nature, Vol. 170, No. 4337, Dec. 13, 1952.

Between October, 1950, and April, 1953, 16 stations were occupied in the Pacific. The velocity and thickness of layers were observed on the following types of structure: deep ocean; deep ocean near islands; Western Pacific; Continental; near deep trenches.

It is considered that the North Pacific basin consists mainly of material of velocity 20,500 ft./sec. at least 8,000 ft. thick, covered by 1,000-2,000 ft. of sediment.

195. *The Problem of Microseisms.*
J. M. Lopez de Azcona, Inst. Geol. Min. Espana, Notas y Comunicaciones, No. 25, pp. 73-84, 1952.

A report of the discussions and resolutions adopted at the international conferences held at Rome in November, 1951, under the direction of the Pontifical Academy of Sciences, on the nature and causes of microseismic disturbances.

196. *Reef Pools sought in Illinois.*
D. A. Morgan, World Oil, Vol. 135, No. 1, pp. 84-86, July 1, 1952.

Five recent reef pool discoveries have aroused new interest in the Illinois basin. They are at Tilden, Frogtown, New Memphis, Okawville and Beaucoup. Intensive geologic and seismic surveys revealed many possibilities of encountering Devonian-Silurian reefs at shallow depth along the western edge of the basin. Geologists and geophysicists are faced with many interpretation problems in finding reef pools. Much has to be ascertained before a more accurate evaluation can be determined.

197. *Seismic Refraction Shooting in the Atlantic.*
Nature, Vol. 70, No, 4331, p. 738, Nov. 1, 1952.

M. N. Hill and J. C. Swallow have developed a method of seismic refraction shooting at sea using hydrophones at a depth of 100 feet below the surface, connected with sono-radio buoys at the surface. Depth-charges exploded at a depth of 900 feet send compressional waves through the sea and the rocks of the sea bed. These P-waves are received on the hydrophones, and the records are transmitted to the ship by signals from the sono-radio buoys. Thus only one ship is necessary for the work. Results of experiments in the Atlantic have been written up by Hill (Phil. Trans. Roy. Soc., A, No. 890, 244, 561, June 17, 1952).

SEISMIC — INSTRUMENTAL

198. *Continuous Velocity Logging.*
G. C. Summers & R. A. Broding, Geophysics, Vol. 17, No. 3, pp. 598-614, July, 1952.

A method for obtaining a continuous well log of formation acoustic compressional velocity is described. The instrument is composed of an acoustic pulse generator separated from a receiver by a five-foot acoustic insulator. Means are provided for generating an acoustic pulse and automatically selecting and recording the first-break travel time as detected by the receiver. The instrument has a range of 5,000 to 25,000 feet per sec. and an accuracy better than 5 %. The log is taken in a conventional well logging manner at speeds of 100-150 feet/min. Typical logs are illustrated along with their probable correlation to seismic reflection horizons and lithology in the borehole.

199. *Seismic Proving Ground.*
J. A. Kornfield, Oil & Gas J., Vol. 51, No. 26, p. 126, Nov. 3, 1952.

The failure of seismic equipment in the field may halt the whole party. Since it is not practical to carry a complete set of spare parts, Carter Oil Co. take precautions against failures. Testing equipment causes, in a short time, wear and tear which normally takes years. Defects are detected quickly and may then be remedied. The methods of testing geophones and cables are described.

200. *Patents.*
Abstracts in Geophysics, Vol. 17, No. 4, p. 952, Oct., 1952.
U.S. 2, 591, 637. 1 April, 1952. Seismic amplifier AVC circuit.
U.S. 2, 591, 795. 8 April, 1952. Moving-coil electromagnetic seismometer.

U.S. 2, 592, 780. 15 April, 1952. Underwater seismometer.
U.S. 2, 593, 052. 15 April, 1952. Suspended-magnet type seismometer.
U.S. 2, 594, 219. 22 April, 1952. Scanner arrangement for displaying seismic reflections.
U.S. 2, 599, 064. 13 May, 1952. Seismograph mixing system.
U.S. 2, 600, 051. 10 June, 1952. Seismic amplifier AVC circuit.
U.S. 2, 601, 543. 24 June, 1952. Moving-coil marine seismometer.

SEISMIC — FIELD TECHNIQUE

201. *Seismic Shooting.*
Oil & Gas J., Vol. 51, No. 22, p. 128, Oct. 6, 1952.

Two new methods of practical application in seismic field operations are described. The first is a hinged support which allows the first section of a dynamite charge to be lowered into a shot-hole and then clamps it whilst successive sections are connected. The second is an improved technique for splicing geophone cables. The stress member is cut, overlapped, and soldered, so that it takes all the tension from the conductors and jacket.

202. *New Aerial Shooting Method announced by Jakosky.*
Petroleum Engineer, Vol. 24, No. 12, p. B-127, November, 1952.
Oil & Gas J., Vol. 51, No. 27, pp. 75-76, Nov. 10, 1952.

It is announced that J. J. Jakosky has developed a new aerial shooting technique involving the use of a powerful bomb. The bomb is ejected from a mortar on the ground. It can be exploded at any required height. This new method is much less expensive than the more conventional ones, and just as effective in many areas. The mortar assembly weighs only 72 lbs which suggests that hitherto inaccessible areas may be explored with this light equipment.

203. *"Mud Flats" Shooting Difficult.*
J. A. Kornfeld, Oil & Gas J., Vol. 51, No. 30, pp. 141-143, December 1, 1952.

Mud flats are flat, muddy, watery wastelands, at times dry but frequently covered with sheets of wind driven water. This article describes the difficulties encountered during seismic surveys over the flats and how they were overcome. Many modifications had to be carried out on equipment and transport.

SEISMIC — INTERPRETATION

204. *Seismic-Problem Panel.*
P. C. Ingalls, Oil & Gas J., Vol. 51, No. 24, p. 78, Oct. 20, 1952.

At the first full meeting of the Geophysical Society of Tulsa, a panel discussion on the need for quality and quantity in velocity surveys was held. L. Y. Faust said that the search for traps was becoming more exacting, necessitating more accurate velocity information. Velocity variations are very great in some areas, and if they were ignored the resulting distortion may hide traps or create false ones. J. E. Owen, R. C. Kendall, and N. Sparks described several inaccuracies of well shooting. F. Cady showed how density varies from area to area. P. L. Lyons suggested that more attention be paid to geology, for complex structures may confuse highly theoretical geophysical interpretations.

205. *Seismograph Interpretation as related to Changes in Sedimentary Section in West Texas and New Mexico.*
J. W. Daly & C. N. Page, Bull. Amer. Ass. Petrol. Geol., Vol. 36, No. 4, pp. 658-676, April, 1952.

The different rock types have characteristic seismic velocities. With a given time-stratigraphic unit this may vary by as much as 300%. Parts of regional velocity maps which demonstrate these maps are shown. The effects of the sharp velocity contrasts on seismic interpretation are assessed.

206. *Relation of Seismic Corrections to Surface Geology.*
H. M. Thralls & R. W. Mossman, Geophysics, Vol. 17, No. 2, pp. 218-228, April, 1952.

The arbitrary application of any set type of near-surface corrections to seismic data can lead to erroneous results. The determination of the type of correction to be used must be based, in part, on the type of formations present in the near surface. Case studies are offered to illustrate various conditions, including use of floating elevation reference planes as compared to a constant datum or a base-of-shot reference.

207. *Up-hole Times.*
J. P. Woods, Geophysics, Vol. 17, No. 2, pp. 229-235, April, 1952.

The up-hole travel time for the seismic impulse from a dynamite explosion is usually taken to depend only on charge depth and formation velocity. In practice this travel time is influenced by charge size, filter setting, instrument sensitivity, and previous history of the shot-hole. In some areas, there occur anomalous up-hole times which are difficult to explain.

208. *Frequency Analysis of Seismic Waves.*
J. J. Jakosky & J. J. Jakosky, Jr., Geophysics, Vol. 17, No. 4, pp. 721-738, Oct., 1952.

This paper contains a brief description of the general factors governing choice of recording media; a description of the instrumentation employed in wave analysis studies; a review of some of the factors involved in the generation of seismic waves, and their propagation; and a few examples of wave separation to illustrate some of the points discussed and their application to seismic exploration.

The results of these studies show that instrumentation of this type is of advantage in those areas where frequency discrimination can improve the signal/interference ratio.

209. *Play-back System aids Seismic Exploration.*
R. Sneddon, Petroleum Engineer, Vol. 24, No. 11, pp. B. 112-120, Oct., 1952.

Conventional seismic records are taken which may be developed after each shot for inspection. At the same time, a special oscillograph produces a broad-band record which may be played back and any number of component separations made. Ordinary motion picture film is used. This is developed in the office, cut into sections covering different shots, and spliced into loops which may be cycled continuously through the reproducer. The excursions of each trace are made to vary the output of photocells. This output is amplified and passed through a heterodyne-type wave-analyser to damp out everything but the desired frequency component. After a play-back of the film, filter settings can be simply determined.

A number of sample recordings are shown to illustrate typical wave interferences and how they are dealt with. The main application of the play-back method is in marginal areas where pour records are obtained.

210. *Salt Solution, a Seismic Velocity Problem in Western Anadarko Basin, Kansas-Oklahoma-Texas.*
M. B. Widess, Geophysics, Vol. 17, No. 3, pp. 481-504, July, 1952.

Solution of salt from a shallow Upper Permian formation in parts of Western Anadarko Basin was observed to produce a pronounced and relatively abrupt velocity change, such as to cause over 300 feet of seismic relief error across a distance of less than three miles. Corehole velocity shooting and velocity profiling were used in the study of the effect of salt solution. The theory, methods, and results of the velocity profiling programme are described. The core-hole velocity data indicate that in the area several environments are present which involve different types of velocity alteration by ground water activity. This kind of phenomenon is considered to be of general significance and related to the spurious representation of surface topography sometimes observed in seismic structural maps.

211. *Studies of a Surface Seismic Disturbance.*

J. D. Eisler, Geophysics, Vol. XVII. No. 3, pp. 550-559, July, 1952.

Seismic studies in a caliche covered area revealed existence of a prominent surface wave group. The dispersive characteristics of this wave group and the existence of retrograde elliptical particle motion place it in a class of Rayleigh waves. Examples of vertical as well as two-component motion are presented.

212. *Comparison of Velocities obtained by Delta-time Analysis and Well Velocity Surveys.*

B. G. Swan & A. Becker, Geophysics, Vol. XVII, No. 3, pp. 575-585, July 1952.

A comparison of the time-depth curves obtained by statistical analysis of delta-times with similar curves from well velocity surveys is presented, representative of results of a study made at a total of 21 wells located in Texas, Oklahoma, Louisiana, Mississippi, Nebraska, and North Dakota. A method applicable to routine studies of delta-times is described. A conclusion is drawn that with average quality reflection data an accuracy of 2 to 3 percent in velocities so obtained may be expected.

213. *Experimental Methods studying Resonance Phenomena in the System Ground-seismograph.* (In Russian).

I. P. Pasechnik, Akad. Nauk S.S.S.R. Izv., Ser. Geofiz. No. 1, pp. 21-34, 1952.

In a ground-seismograph system, natural vibrations can appear which interfere with the waves from a shot. These vibrations, which make interpretation more difficult, are greater when the seismograph is placed on marshy ground or soft soil. Observation and measurement of the vibrations can be made in three different ways. Firstly, the impulse method: this consists of striking the seismograph lightly and recording the vibrations. The record is compared with a seismogram made by the same instrument. Secondly, a train of sinusoidal vibrations which begin and end abruptly are applied. For this purpose, two electrodynamic seismographs are rigidly connected and waves of a desired frequency are fed into one which produce mechanical vibrations. These vibrations are recorded by the second seismograph. Thirdly, the improved stationary method; vibrations are recorded by a cathode-ray oscillograph with electronic commutator.

214. *A Seismic Velocity Logging Method.*

C. B. Vogel, Geophysics, Vol. XVII, No. 3, pp. 586-597, 1952.

A transient sound pulse is employed in a seismic velocity well logging method. The transmitter and receiver are 5 feet apart. They are lowered into the well and sound pulses are produced at 5 feet intervals. The refracted 'P' wave, through the wall of the well, is received first.

For limestones, P, S, water, and surface waves have been recorded. There are modifications for variation of the well diameter. Results are compared with seismic, electric log, and velocity log data.

215. *Studies of a Surface Seismic Disturbance.*

J. D. Eisler, Geophysics, Vol. XVII, No. 3, pp. 550-559, July, 1952.

Seismic studies in a caliche-covered area revealed existence of a prominent surface wave group. The dispersive characteristics of this wave group and the existence of retrograde elliptical particle motion place it in a class of Rayleigh waves, Examples of vertical as well as two-component motion are presented.

GRAVITY — GENERAL

216. *Gravimeter Observations comparing Pendulum Stations at Cambrdige, York, Newcastle-upon-Tyne, Edinburgh and Aberdeen.*

W. Bullerwell, Mon. Not. Roy. Astr. Soc., Geophys. Suppl., Vol. 6, No. 5, May, 1952.

An extensive network of gravimeter stations has been observed by the Geological Survey of Great Britain using a Frost Gravimeter. In the course of this survey gravimeter observations were made at recent pendulum stations in York, Newcastle-upon-Tyne, Edinburgh and Aberdeen. At these stations the gravimeter determinations gave values for differences in gravity from Pendulum House, Cambridge, which were consistent with the pendulum observations of Browne, Cook, McCarthy and Parasnis (1950).

The observations are given, and from them the calibration factor of the Frost Meter is deduced. Reasons for the departure of this factor from the previously accepted figure are investigated and discussed.

217. *Gravimetry Measurements in the English Channel.*

B. C. Browne & R. I. B. Cooper, Proc. Roy. Soc., No. B896, p. 426, April 24, 1952.

In 1948 gravity measurements were made in a submarine, 43 stations in the English Channel and at Portland, Devonport, Gosport and Cherbourg. There are also five stations in the area at which measurements were made in 1946. Tables are given of the details of the gravity measurements and of the free air, Bouguer and isostatic anomalies (Airy-Heiskanen, crustal thickness 30 km). The anomalies are shown to be compatible with an interpretation of existing knowledge of the Mesozoic geology of the Channel basin provided that reasonable assumptions are made. An area of strong negative anomalies off the French Coast in the Cherbourg—Le Havre area extends about half-way across the Channel. These must be explained by intra-crustal masses. The anomalies show the same trend to positive values in the west as is found in the British Isles and Northern France.

218. *Tidal Gravity Observations at Winsford (Cheshire).*

R. Tomaschek, Mon. Not. Roy. Astr. Soc., Vol. 6, Sept. 1952.

Tidal observations have been performed in the I.C.I. Salt Mine at Winsford. The gravimetric factor has been determined both for the overall values and the principal harmonic constituents. Its value is $G = 1.20 \pm 0.04$. The results are compared with former measurements.

219. *The Danish Gravity Reference Stations.*

Geodaetisk Institut, Meddelelse No. 25, 1952.

A detailed description of all Danish gravity reference stations together with the fixed values of the effective gravity on the stations given in the Potsdam system. New connecting measurements (1951-2) are taken into consideration.

220. *Use of the Wave Height Operational Index in Planning Offshore Gravity Meter Surveys.*

A. H. Glenn & R. W. James, Geophysics, Vol. XVII, No. 4, pp. 924-935, Oct., 1952.

Efficiency of offshore gravity meter exploration (stations occupied daily) is analyzed statistically as a function of wave height. For the surveys investigated, the number of stations occupied daily can be best be represented by the line of regression, $Yc = 49.85 - 8.75 X$, where X equals wave height and Yc equals the number of stations. Cost of offshore gravity meter surveys is shown to vary as much as 50% depending on planning involving sea conditions. Application of forecasts of sea and weather conditions is discussed and savings achieved through their use are demonstrated.

GRAVITY — INTERPRETATION

221. *Logarithmic Master Charts for Gravitational Survey.* (In Russian).
A. A. Nepomnyashchikh, Akad. Nauk. S.S.S.R. Izv., Ser. Geofiz., No. 1, pp. 40-46, 1952.

A new equation was derived and from it 66 master charts were constructed for bodies of different geometrical shapes, buried parallel to the surface of the earth or inclined to it. These charts were found very useful in interpreting the results of gravitational surveys.

222. *Mountains and Gravity.*
P. Evans, Nature, Vol. 169, No. 4313, pp. 1079-80, June 28, 1952.

Until recently, no attempt had been made to evaluate the gravitational effects of surface rocks in a large area where a great thickness of sediments is present, but this has been done in an extensive gravity survey of parts of India and Burma, the results of which have been published by the Geological Society of London, (Quart. J. Geol. Soc., 102, 211 (1946).

The various investigations of gravity anomalies have shown: first, that the basic assumptions of the Pratt-Hayford-Bowie hypothesis are quite untenable; secondly, that allowance must be made for the effects of surface geology; and thirdly, that there are large areas of the earth's crust, particularly those where there has been recent mountain building, which are not in isostatic equilibrium.

223. *Isostatic Compensation of Light Masses situated beneath the Geoid. Application to the Interpretation of the Isostatic Anomalies of the Paris Basin.* (In French).
S. Coron, Acad. Sci. Paris Comptes Rendus, Tome 234, No. 9, pp. 977-979, 1952.

Density differences of topographic masses and of terrain at lower levels are important in the interpretation of isostatic anomalies. Use of the Cassinis tables indicates the importance not so much of the total mass of sediments but of their distribution and relative dimensions. Two isostatic anomaly maps are shown, one calculated according to the Airy hypothesis with depth of compensation of 40 km., and the other assuming a basin composed of sediments of density 2.3.

GRAVITY — THEORY & RESEARCH

224. *Subsurface Gravity Measurements.*
G. R. Rogers, Geophysics, Vol. XVII, No. 2, pp. 365-377, April, 1952.

Gravity data were obtained at approximately 100 foot intervals in a vertical mine shaft 2,916 feet deep. The shaft passed through a region of high positive density contrast, and a local anomaly was observed of plus 14.0 gravity units to minus 17.9 units. Calculations for Bouguer densities were carried out with the gravity measurements. A theoretical sphere that closely approximates the observed data and known conditions is derived from the gravity data.

225. *The Variation of Gravity within the Earth.*
S. Saxov, Tellus, Vol. 4, No. 2, pp. 138-140, May, 1952.

The different methods for determining the values of gravity within the earth are reviewed. Using the density values by Ramsay (1949) the variation of gravity has been tabulated and is shown in a graph.

226. *A Study of Rock Densities in the English Midlands.*
D. S. Parasnis, Mon. Not. Roy. Astr. Soc., Geophys. Suppl., Vol. 6, No. 5, May, 1952.

This paper describes the results of field and laboratory experiments on the rocks in the Midlands of England. Density measurements were made on nine geological formations from the Silurian to the Cretaceous and also on metamorphic rocks from the Malvern area. A catalogue of densities has been prepared for general use based on the assumption that rocks in the field are saturated with water. A table of densities and porosities for a large number of rocks is also given. Among the conclusions drawn about the observed sampling variances, the most significant is that rock formations in the West Midlands do not appear to show any "regional variation" of density.

227. *Tidal Gravity Experiments at Peebles and Kirklington.*
L. H. Tarrant, Mon. Not. Roy. Astr. Soc., Geophys. Suppl. Vol. 6, No. 5, May, 1952.

Two field gravity meters were read continuously for a period of 14 days, one at Peebles in South Scotland, the other at Kirklington near Nottingham. The experiments have shown that the observed variations of gravity were proportional to the predicted tide-raising force to within a standard deviation of 0.02 milligal. The factors of proportionality are 1.02 for Kirklington, and 1.10 for Peebles. There were no significant phase differences on the average; the individual phase differences were rather irregular.

228. *Harmonic Analysis of Tidal Gravity Experiments at Peebles and Kirklington.*
R. Tomaschek, Mon. Not. Roy. Astr. Soc., Geophys. Suppl., Vol. 6, No. 5, May, 1952.

Simultaneous tidal gravity measurements at Peebles and Kirklington over a period of 14 days have been analysed harmonically. The diurnal terms K_1 and O_1 give a ratio of observed to theoretical amplitude of $G = 1.1$ without signifant phase difference. The semi-diurnal terms show a phase lag of about 10° and $G = 1.2$ at Kirklington and $G = 1.1$ at Peebles. This difference is explained as due to regional influences of sea-tides. $G = 1.10$ to 1.15 is regarded as the most probable value resulting out of these observations. The influence of temperature and pressure is discussed and the existence of a 24-hour period of non-gravitational origin ("thermal tide") confirmed. The most probable values of Love's numbers "k" and "h" and the geophysical consequences as to the properties of the interior of the Earth are discussed.

229. *A Measurement of the Difference of Gravity between the National Physical Laboratory, Teddington and the Ordnance Survey Office, Southampton.*
A. H. Cook, Mon. Not. Roy. Astr. Soc., Geophys. Suppl., Vol. 6, No. 5, May, 1952.

Using the Cambridge pendulum appartus the value of gravity at the National Physical Laboratory has been found to be 69.90 ± 16 mgal. greater than that at the Ordnance Survey Office at Southampton. The result of a measurement with a Worden gravimeter was 70.36 mgal., and other indirect gravity measurements are in satisfactory agreement with the pendulum result.

MAGNETIC — GENERAL

230. *Geological Mapping, Structural Problems and the Magnetometer.*
W. K. Buck, Trans. Can. Inst. Min. & Metall., Vol. 54, pp. 370-374, 1951.

A detailed description of the mapping of a highly magnetic diabase dyke with the aid of a Sharpe vertical magnetometer. This survey aimed at the location of two faults which were supposed to have offset the dyke. The absence of the traverse map and some of the magnetic profiles hinders the reading of this paper.

231. *Magnetic Prospecting Methods in Asbestos Exploration.*
J. H. Low, Trans. Can. Inst. Min. & Metall., Vol. 54, pp. 388-395, 1951.

In a search for asbestos ore bodies along the northern edge of the Thetford-Black Lake, it was possible to distinguish between anomalies caused by barren granite and those caused by potential ore bodies. It is considered that magnetic surveying in close conjunction with geological field observations is a valuable guide to direct prospective drilling for asbestos.

232. *Magnetometer Surveys in New Mexico Areas.*
J. L. Harper, Petroleum, Vol. 24, No. 9, pp. B-14-16, August, 1952.

Parts of New Mexico have been surveyed by airborne magnetometer and the resulting contour maps have been released by the U.S. geological survey. Since then, two ground magnetometer surveys, based upon beds in the sedimentaries, have been completed in the area. Results of the latter disagree with those of the former, but the highs of the ground magnetometer survey agree with structures determined from surface geology, except that they are offset a little. Examples are given which illustrate this, and others which illustrate the comparison between the airborne magnetometer results and geology.

233. *First Air Survey made for Costa Rica.*
Petroleum Engineer, Vol. 24, No. 11, pp. B. 12-16, Oktober, 1952.

A 2100 sq. mls. air survey of the eastern coastal plains of Cocta Rica has been conducted. It is hoped to outline the sedimentary basin, determine the thickness of the sedimentary section, and judge the effect of volcanics.

First, 66 flights were made at 21,000 ft. to obtain 882 photos at a scale of 1 : 40,000. From these photo-maps were compiled. Then the magnetometer survey commenced, using a high-sensitivity Gulf airborne magnetometer. Variations in magnetic intensity of 1 gamma were measured.

MAGNETIC — THEORY & RESEARCH

234. *Magnetic Anomalies over Oceanic Structures.*
F. Press & M. Ewing, Trans. Amer. Geophys. Un., Vol. 33, pp. 349-55, June, 1952.

The importance of the airborne magnetometer as a geophysical tool, in the study of oceanic structures is stressed. Theoretical anomalies of the total magnetic vector are computed for typical oceanic structures to aid in the planning of aerial surveys. These structures are:—(1) a volcanic island; (2) a crustal fold associated with a negative strip; (3) a continental border.

235. *Structural Correlation of Micromagnetic and Reflection Surveys.*
W. P. Jenny, World Oil, Vol. 134, No. 4, pp. 67-72, 1952.

Micromagnetic surveys, measuring and interpreting weak anomalies of the order of 2.5 gammas, may locate sedimentary structures favourable to the accumulation of oil. The surveys are best carried out by using an airborne magnetometer in a helicopter.

The gravity and magnetic field associated with a favourable structure can affect the deposition of sediments laid down in a normal sequence after the formation of the original structures. The change in deposition will affect seismic velocities as well as the magnetic susceptibility of the sedimentary column above the structure. Four hypothetical cases of anticlines with velocity difference over the crests and flanks are shown, and in three cases erroneous interpretation of the reflection results can be obtained.

In four areas where drilling was carried out after reflection surveys, better results would have been obtained if the micromagnetic evidence had been used in conjunction.

ELECTRICAL

236. *Attenuation of Radio Frequency Waves through the Earth.*
W. C. Pritchett, Geophysics, Vol. XVII, No. 2, pp. 193-217, April, 1952.

Evidence has been presented by several investigators indicating the possibility that radio waves penetrate sufficiently into the earth to be useful in prospecting for oil.

Conventional electromagnetic theory used with normal values of the earth constants indicates, however, that the attenuation is too great to allow the signal to be used after propagation through significant distances of shale.

To settle the above question an experiment was conceived and carried out in which the signal level in the earth was measured at various distances from a battery-operated transmitter operating at 1,652 k/c suspended in an uncased, mud-filled hole, by a mud-saturated rope. The mud resistivity was matched to that of the 40 ft. thick shale section used in order that the entire immediate region would be as nearly as possible homogeneous. The receiver was also battery-operated and suspended by a cable in other similar mud-filled holes, at various distances from the first hole.

The attenuation constant in shale was found to be .18 nepers/ft. (1.56 db/ft.), which is much too large to give any hope of deep penetration. A few measurements in a limestone section gave a value of .086 nepers/ft., which is also too large to be useful. Although these values are quite high, they are lower than theory predicts for these earth resistivities by a factor of about 3.

237. *Some New Developments of the Geoelectrical Resistance Method.*
A. Huber, Elektrotech. u. Maschineb. (EuM) 69, 1-10, Jan. 1, 1952. (In German).

(A theoretical paper on the interpretation of experimental results in terms of structure of the earth's surface. The two and three-layer problems are examined and then the theory is extended to several more difficult problems including a layer with continuously varying resistivity and special problems met with in mountain valleys and mines. The Schlumberger and Wenner methods of electrode spacing are discussed and it is shown that the further apart the potential electrodes are, the smaller the variation in measured resistivity due to surface irregularities.

238. *The Cylindrical Ore Body in the Presence of a Cable carrying an Oscillating Current.*
J. R. Wait, Geophysics, Vol. XVII, No. 2, pp. 378-386, April, 1952.

The problem of an infinite cable carrying an oscillating current parallel to a conducting cylinder is solved. The homogeneous electrical properties of the media inside and outside the cylinder can be arbitrary. The special case is considered in detail where the exterior medium is a relatively poor conducting medium. The application to geophysical prospecting for massive sulphide ore zones is discussed.

239. *Patents.* Abstracts in Geophysics. Vol. XVII, No. 2, p. 395, April, 1952.
U.S. 2,573, 682. N Nov. 1951. Means and Method for Electromagnetic-Wave Investigation.
U.S. 2, 575, 340. 20 Nov. 1951. An Electromagnetic Prospecting System.
U.S. 2, 575, 349. 20 Nov. 1951. A System for Electrical Exploration.

OTHER METHODS

240. *Radioactive Oil Survey Technique.*
Dr. J. W. Merritt, World Oil, Vol. 135, No. 1, pp. 78-82, July 1, 1952.

Hydrocarbon gases, given off by oil pool, tend to break the surface directly above the pool and are invariably more concentrated at its edges. This gas movement causes increased water evaporation in the soil, which is followed by the creeping of adjacent moisture into the affected area. The fater brings with it soluble minerals which are left behind after evaporation. Hence a halo of soil with high mineral content is formed. Some of these minerals are radioactive. Geiger counters and scintillometers are used to detect the radiations. Various geological irregularities that cause changes in radiation strength are mentioned. Field technique and interpretation are briefly discussed.

241. *Counter gives Radiometric Analysis of Uranium Ores.*
Mining World, 75, p. 30, May, 1951.

A short description of the light-weight Geiger counter (Model 600) of Minerals Engineering Co. It serves many purposes such as: field exploration, logging of boreholes, analysis of samples. For the latter an accuracy of 0.02 % U_3O_8 is claimed by the manufacturer.

242. *The Exploration and Developments of Canadian Uranium Deposits.*
B. S. W. Buffam & E. B. Gillanders, Trans. Can. Inst. Min. & Metall., Vol. 54, pp. 434-437, 1952.

A discussion on the standard practices adopted by the Eldorado Mining and Refining Ltd. in the exploration and development of uranium ores. The Geiger Muller counter plays an important part in surface surveying, sample testing, and borehole logging.

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